Sudan University of Science and Technology
College of Post-Graduation studies

MATERIAL SELECTION FOR AN ENGINE EXHAUST OF A UTVA 75 LIGHT AIRCRAFT USING A SYSTEMATIC APPROACH

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Thesis submitted in Partial fulfillment of the requirements for the Degree of M.Sc. in Mechanical Engineering (Production)

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قال تعالى:

وَهُوَ اللَّهُ لَا إِلَٰهَ إِلَّا هُوَ ۖ لَهُ الْحَمْدُ
فِي الْأُولَىٰ وَالْآخِرَةِ ۖ وَلَهُ الْحُكْمُ
وَإِلَيْهِ تُرْجَعُونَ

صدق الله العظيم

DEDICATION

To my family for the valuable time I have taken from them
and the constant motivation they have given me.

To my friends and colleagues for pushing me to excel
infinitely and indefinitely.

And most importantly to the beautiful people of my home
*country Sudan***.**

ACKNOWLEDGMENT

I would like to sincerely thank Dr. Yasin Mohammed hamdan for the valuable guidance he has provided to complete this thesis. Many thanks to all the personnel at the air force college in Portsudan for their assistance in helping me understand the aircraft and its operation as well as its problems. I would like to also acknowledge all the professors at the Mechanical Engineering department in Sudan University of Science and technology for passing on their knowledge which was invaluable in writing this thesis.

ABSTRACT

The Sudanese air force college trains its pilots using a world-renowned light aircraft for basic pilot training called UTVA-75, during operation in the climate of Portsudan the exhaust tubes experienced failure in the shape of cracking and therefore become dangerous to operate. The study tackles the issue from a material point of view, as properties that eliminate or reduce cracking or any failure are essentially material properties. The research examines material selection methods to identify a method that implements a systematic approach to selection, provides a ranking process, bases its selection on material properties and incorporate a material database for selection. Michael Ashby’s method was selected above methods used in material selection such as cost vs performance, failure analysis, value analysis, benefit cost analysis and preferential ranking after it fulfilled the research requirements. Fracture toughness and density were the two properties that material selection was based on and upon implementing the method stainless steel was identified as the suitable material for the exhaust pipe. The results were compared to exhaust pipes of aircrafts which were similar in category to the Utva 75 aircraft to verify the results. The results however did not identify the exact grade of stainless steel and further studies are required to correctly identify the grade of stainless steel.

مستخلص

تدرب كلية القوات الجوية السودانية الطياريين باستخدام طائرة خفيفة ذات شهرة عالمية للتدريب الأساسي تدعىUTVA-75 ، أثناء الطيران في مناخ بورتسودان ، عانت أنابيب العادم من فشل في شكل تصدع وبالتالي أصبحت خطرة في العمل. تتناول الدراسة هذه المسألة من وجهة نظر المواد ، حيث أن الخصائص التي تقضي على التشققات أو تقللها أو أي عطل تعتبر من الخصائص المواد. يبحث البحث في طرق اختيار المواد لتحديد الطريقة التي تطبق منهجية ممنهجة للاختيار ، و تطبق عملية تصنيف للمواد ، وتستند في اختيارها على خواص المواد وتحتوي على قاعدة بيانات لاختيار المواد. تم اختيار طريقة مايكل آشبي أعلاه بعد مراجعة الأساليب المستخدمة في اختيار المواد مثل التكلفة مقابل الأداء ، وتحليل الفشل ، وتحليل القيمة ، وتحليل تكلفة المنافع والتصنيف التفضيلي بعد استيفائها لمتطلبات البحث. كانت صلابة الكسر والكثافة هما الخواصان اللتان استند إليهما اختيار المواد وبناءً على الطريقة التي تم بها تحديد الفولاذ المقاوم للصدأ على أنه المادة المناسبة لأنبوب العادم. وتمت مقارنة النتائج بأنابيب عوادم الطائرات التي كانت متشابهة في الفئة مع طائرة Utva 75للتحقق من النتائج. ومع ذلك ، فإن النتائج لم تحدد بالضبط درجة الفولاذ المقاوم للصدأ وهناك حاجة إلى مزيد من الدراسات لتحديد درجة الفولاذ المقاوم للصدأ بشكل صحيح.

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CHAPTER I

INTRODUCTION

Introduction

1.1 Preface

Engineering material have evolved rapidly in the past century, and the industrial community has taken advantage of that huge expansion in delivering quality products that are cheaper, stronger and better resistant to corrosion. The study intends to improve on the mechanical properties of an exhaust system utilizing the vast material library available, but in order to achieve this a systematic and scientific approach will be implemented to determine the suitable material for the failing exhaust system of an aircraft. The study will, in the end, conclude as to whether the systematic approach has been successful in selecting a new material with better mechanical properties.

1.2 Problem statement

The aviation college located in Portsudan houses several light aircrafts for basic pilot training. The most common is the UTVA 75 two-seater Lycoming engine. Due to rigorous training schedule, high operating temperatures, and lack of proper maintenance; cracking is seen visible at the connecting ends of the exhaust pipes (figure 1.1, 1.2) causing excess noise and potential for accidents should the exhaust fall apart during flight.

1.3 Purpose of study

The purpose of the study is to determine the suitable material for the UTVA 75 aircraft engine exhaust according to a systematic approach in order to reduce or eliminate the exhaust failures.

The study will then compare the results obtained with an aircraft with the same variant to see if the results obtained are relative.

Figure 1.1: Utva 75 exhaust crack

Figure 1.2: UTVA 75 exhaust crack

1.4 Objectives

- Selecting an optimum material for the exhaust of the UTVA 75 aircraft
- Comparing the obtain results to similar aircraft exhaust materials.

1.5 Method

The method which will be used for material selection will be shall be a method that:

- uses a systematic approach to ensure the repeatability of results
- Incorporate a material database where selection is made
- It must have a ranking method, as material sometimes can withstand loads but have high cost therefore making it unfit for selection
- Is based on the mechanical properties of materials, making the selection process scientific rather than being opinion based.

CHAPTER II

LITERATURE REVIEW

2.1 Engineering materials

Materials are probably more deeply seated in our culture than most of us realize. Transportation, housing, clothing, communication, recreation, and food production— virtually every segment of our everyday lives is influenced to one degree or another by materials. Historically, the development and advancement of societies have been intimately tied to the members' ability to produce and manipulate materials to fill their needs. In fact, early civilizations have been designated by the level of their materials development (Stone Age, Bronze Age, Iron Age).

The earliest humans had access to only a very limited number of materials, those that occur naturally: stone, wood, clay, skins, and so on. With time, they discovered techniques for producing materials that had properties superior to those of the natural ones; these new materials included pottery and various metals. Furthermore, it was discovered that the properties of a material could be altered by heat treatments and by the addition of other substances. At this point, materials utilization was totally a selection process that involved deciding from a given, rather limited set of materials, the one best suited for an application by virtue of its characteristics. It was not until relatively recent times that scientists came to understand the relationships between the structural elements of materials and their properties.

This knowledge, acquired over approximately the past 100 years, has empowered them to fashion, to a large degree, the characteristics of materials. Thus, tens of thousands of different materials have evolved with rather specialized characteristics that meet the needs of our modern and complex society, including metals, plastics, glasses, and fibers (figure 2.1).

The development of many technologies that make our existence so comfortable has been intimately associated with the accessibility of suitable materials. An advancement in the understanding of a material type is often the forerunner to the stepwise progression of a technology. For example, automobiles would not have been possible without the availability of inexpensive steel or some other comparable substitute. In the contemporary era, sophisticated electronic devices rely on components that are made from what are called semiconducting materials. (Callister & Rethwisch, 2013)

Many times, a materials problem is one of selecting the right material from the thousands available. The final decision is normally based on several criteria. First, the in-service conditions must be characterized, for these dictate the properties required of the material. On only rare occasions does a material possess the maximum or ideal combination of properties. Thus, it may be necessary to trade one characteristic for another. (Callister & Rethwisch, 2013)

The classic example involves strength and ductility; normally, a material having a high strength has only a limited ductility. In such cases, a reasonable compromise between two or more properties may be necessary. A second selection consideration is any deterioration of material properties that may occur during service operation. For example, significant reductions in mechanical strength may result from exposure to elevated temperatures or corrosive environments

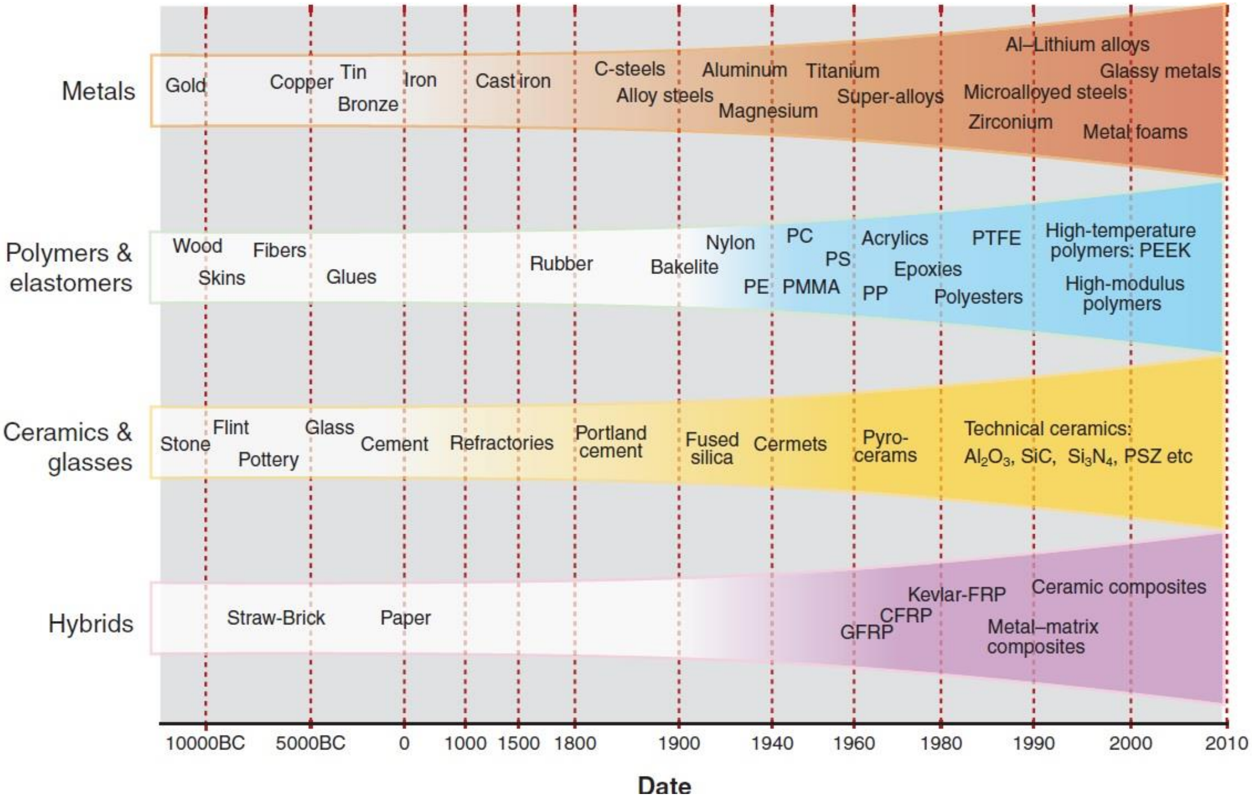


Figure 2.1 the history of materials

2.1.1 Material classification

Solid materials have been conveniently grouped into three basic categories: metals, ceramics, and polymers, a scheme based primarily on chemical makeup and atomic structure. Most materials fall into one distinct grouping or another. In addition, there are the composites that are engineered combinations of two or more different materials. A brief explanation of these material classifications and representative characteristics is offered next (figure 2.2). Another category is advanced materials—those used in high-technology applications, such as semiconductors, biomaterials, smart materials, and nanoengineered materials.

2.1.1.1 Metals

Metals are composed of one or more metallic elements (e.g., iron, aluminum, copper, titanium, gold, nickel), and often also nonmetallic elements (e.g., carbon, nitrogen, oxygen) in relatively small amounts. Atoms in metals and their alloys are arranged in a very orderly manner and are relatively dense in comparison to the ceramics and polymers With regard to mechanical characteristics, these materials are relatively stiff and strong, yet are ductile (i.e., capable of large amounts of deformation without fracture), and are resistant to fracture which accounts for their widespread use in structural applications. Metallic materials have large numbers of nonlocalized electrons—that is, these electrons are not bound to particular atoms. Many properties of metals are directly attributable to these electrons. For example, metals are extremely good conductors of electricity and heat, and are not transparent to visible light; a polished metal surface has a lustrous appearance. In addition, some of the metals (i.e., Fe, Co, and Ni) have desirable magnetic properties. shows several common and familiar objects that are made of metallic materials. (Callister & Rethwisch, 2013)

Metals have relatively high stiffness, measured by the modulus, E. Most, when pure, are soft and easily deformed, meaning that σy is low. They can be made strong by alloying and by mechanical and heat treatment, increasing σy, but they remain ductile, allowing them to be formed by deformation processes. And, broadly speaking, they are tough, with a usefully high fracture toughness K1c. They are good electrical and thermal conductors. But metals have weaknesses too: they are reactive; most corrode rapidly if not protected (Ashby, et al., 2007)

2.1.1.2 Ceramics

Ceramics are compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides, and carbides. For example, common ceramic materials include aluminum oxide (or alumina, Al_2O_3), silicon dioxide (or silica, SiO_2), silicon carbide (SiC), silicon nitride (Si_3N_4), and, in addition, what some refer to as the traditional ceramics—those composed of clay minerals (e.g., porcelain), as well as cement and glass. With regard to mechanical behavior, ceramic materials are relatively stiff and strong—stiffnesses and strengths are comparable to those of the metals. In addition, they are typically very hard. Historically, ceramics have exhibited extreme brittleness (lack of ductility) and are highly susceptible to fracture. However, newer ceramics are being engineered to have improved resistance to fracture; these materials are used for cookware, cutlery, and even automobile engine parts. Furthermore, ceramic materials are typically insulative to the passage of heat and electricity (i.e., have low electrical conductivities) and are more resistant to high temperatures and harsh environments than are metals and polymers. With regard to optical characteristics, ceramics may be transparent, translucent, or opaque, and some of the oxide ceramics (e.g., Fe_3O_4) exhibit magnetic behavior. (Callister & Rethwisch, 2013)

Ceramics are non-metallic, inorganic solids, like porcelain or alumina—the material of spark-plug insulators. They have many attractive features. They are stiff, hard and abrasion resistant, they retain their strength to high temperatures, and they resist corrosion well. Most are good electrical insulators. They, too, have their weaknesses: unlike metals, they are brittle, with low K1c. This gives ceramics a low tolerance for stress concentrations (like holes or cracks) or for high contact stresses (at clamping points, for instance). For this reason, it is more difficult to design with ceramics than with metals.

2.1.1.3 Glasses

Glasses are non-crystalline (‘amorphous’) solids. The commonest are the soda-lime and borosilicate glasses familiar as bottles and Pyrex ovenware, but there are many more. The lack of crystal structure suppresses plasticity, so, like ceramics, glasses are hard and remarkably corrosion resistant. They are excellent electrical insulators and, of course, they are transparent to light. But like ceramics, they are brittle and vulnerable to stress concentrations. (Ashby, et al., 2007)

2.1.1.4 Polymers

Polymers include the familiar plastic and rubber materials. Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements (i.e., O, N, and Si). Furthermore, they have very large molecular structures, often chainlike in nature, that often have a backbone of carbon atoms. Some common and familiar polymers are polyethylene (PE), nylon, poly (vinyl chloride) (PVC), polycarbonate (PC), polystyrene (PS), and silicone rubber. These materials typically have low densities whereas their mechanical characteristics are generally dissimilar to those of the metallic and ceramic materials—they are not as stiff or strong as these other material types. However, on the basis of their low densities, many times their stiffnesses and strengths on a per-mass basis are comparable to those of the metals and ceramics. In addition, many of the polymers are extremely ductile and pliable (i.e., plastic), which means they are easily formed into complex shapes. In general, they are relatively inert chemically and unreactive in a large number of environments.

One major drawback to the polymers is their tendency to soften and/or decompose at modest temperatures, which, in some instances, limits their use. Furthermore, they have low electrical conductivities and are nonmagnetic. (Callister & Rethwisch, 2013)

Polymers are light—their densities ρ are less than those of the lightest metals. Compared with other families they are floppy, with moduli E that are roughly 50 times less than those of metals. But they can be strong, and because of their low density, their strength per unit weight is comparable to that of metals. Their properties depend on temperature so that a polymer that is tough and flexible at room temperature may be brittle at the -4°C of a household freezer, yet turn rubbery at the 100°C of boiling water. Few have useful strength above 150°C. If these aspects are allowed for in the design, the advantages of polymers can be exploited. And there are many. They are easy to shape (that is why they are called plastics): complicated parts performing several functions can be molded from a polymer in a single operation. Their properties are well suited for components that snap together, making assembly fast and cheap. And by accurately sizing the mold and pre-coloring the polymer, no finishing operations are needed. Good design exploits these properties.

Elastomers—the material of rubber bands and running shoes—are polymers with the unique property that their stiffness, measured by E, is extremely low (500–5000 times less than those of metals) and their ability to be stretched to many times their starting length yet recover their initial shape when released. Despite their low stiffness they can be strong and tough—for example car tires (Ashby, et al., 2007)

2.1.1.5 Composites

A composite is composed of two (or more) individual materials that come from the categories previously discussed—metals, ceramics, and polymers. The design goal of a composite is to achieve a combination of properties that is not displayed by any single material and also to incorporate the best characteristics of each of the component materials. A large number of composite types are represented by different combinations of metals, ceramics, and polymers.

One of the most common and familiar composites is fiberglass, in which small glass fibers are embedded within a polymeric material (normally an epoxy or polyester). The glass fibers are relatively strong and stiff (but also brittle), whereas the polymer is more flexible. Thus, fiberglass is relatively stiff, strong, and flexible. In addition, it has a low density. Another technologically important material is the carbon fiber–reinforced polymer (CFRP) composite—carbon fibers that are embedded within a polymer. These materials are stiffer and stronger than glass fiber–reinforced materials but more expensive. CFRP composites are used in some aircraft and aerospace applications, as well as in high-tech sporting equipment (e.g., bicycles, golf clubs, tennis rackets, skis/snowboards) and recently in automobile bumpers. The new Boeing 787 fuselage is primarily made from such CFRP composites. (Callister & Rethwisch, 2013)

Hybrids, another name for composites, are combinations of two (or more) materials in an attempt to get the best of both. Glass and carbon-fiber-reinforced polymers (GFRP and CFRP) are hybrids; so, too, are sandwich structures, foams and laminates. And almost all the materials of nature (wood, bone, skin, leaf) are hybrids—bone, for instance, is a mix of collagen (a polymer) with hydroxyapatite (a mineral). Hybrid components are expensive and they are relatively difficult to form and join. So, despite their attractive properties the designer will use them only when the added performance justifies the added cost. (Ashby, et al., 2007)

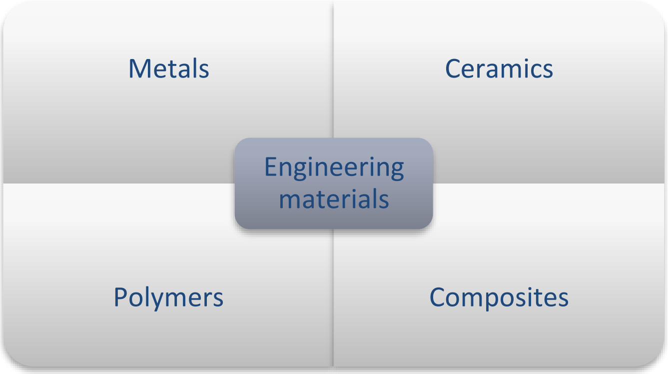


Figure 2.2 classification of material according to William D. Callister

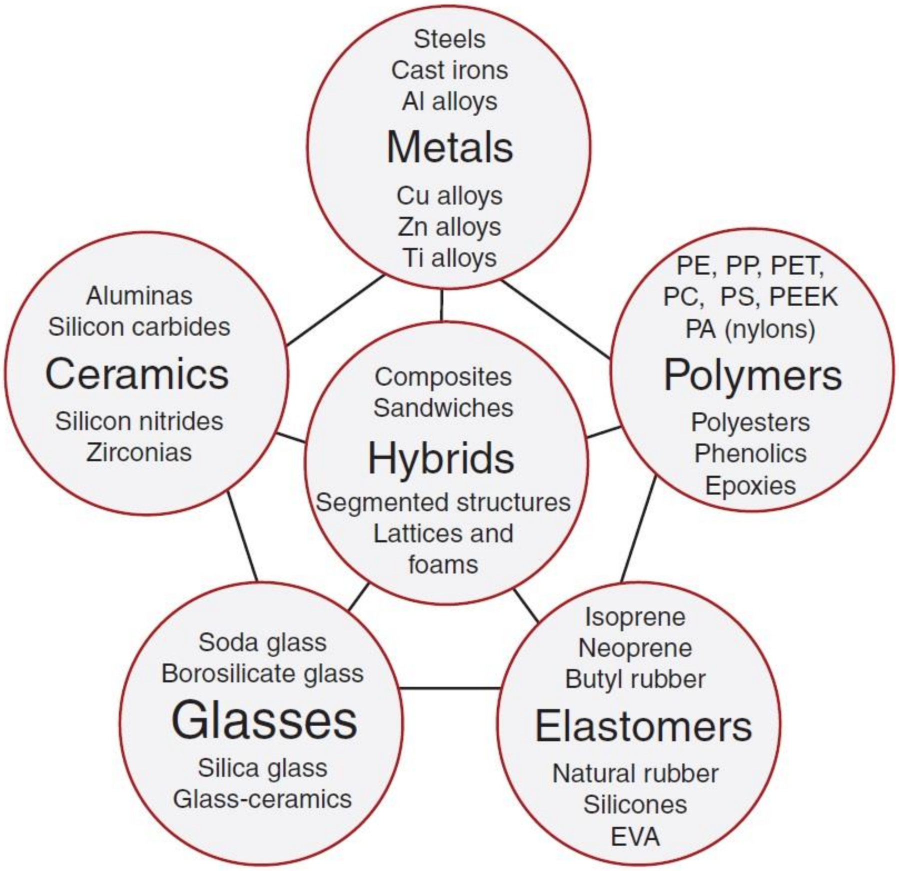


Figure 2.3 Classification of materials according to Michael Ashby

2.1.2 Mechanical properties

Mechanical properties represent one of many material properties that define materials. Mechanical properties determine a material's behavior when subjected to mechanical stresses. Properties include elastic modulus, ductility, hardness, and various measures of strength the mechanical properties of materials are ascertained by performing carefully designed laboratory experiments that replicate as nearly as possible the service conditions. Factors to be considered include the nature of the applied load and its duration, as well as the environmental conditions. It is possible for the load to be tensile, compressive, or shear, and its magnitude may be constant with time, or it may fluctuate continuously. Application time may be only a fraction of a second, or it may extend over a period of many years. Service temperature may be an important factor.

2.1.2.1 Toughness

Toughness is a mechanical term that may be used in several contexts. For one, toughness (or more specifically, fracture toughness) is a property that is indicative of a material's resistance to fracture when a crack (or another stress-concentrating defect) is present. Because it is nearly impossible (as well as costly) to manufacture materials with zero defects (or to prevent damage during service), fracture toughness is a major consideration for all structural materials. Another way of defining toughness is as the ability of a material to absorb energy and plastically deform before fracturing. For dynamic (high strain rate) loading conditions and when a notch (or point of stress concentration) is present, notch toughness is assessed by using an impact test. For the static (low strain rate) situation, a measure of toughness in metals (derived from plastic deformation) may be ascertained from the results of a tensile stress–strain test. It is the area under the s–P curve up to the point of fracture. The units are the same as for resilience (i.e., energy per unit volume of material). For a metal to be tough, it must display both strength and ductility. (Callister & Rethwisch, 2013)

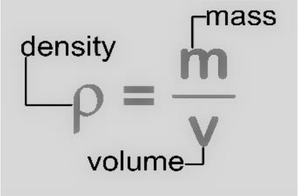
2.1.2.2 Fracture toughness

Fracture toughness is defined as the stress-intensity factor at a critical point where crack propagation becomes rapid. It is given the symbol K1c and is measured in units of megapascals times the square root of the distance measured in meters (MPa √m). With glass, an extremely brittle material, having a K1c value of 1, all other materials can be assigned values relative to that of glass. Metals thus have relative K1c's in the 30–45 range (aluminum alloys) or the 40–65 range (steels). In comparison, conventional ceramics have relative a fracture toughness in the 3–4 range and are therefore brittle like glass. Ceramics with fibrous or interlocked microstructures and particle-reinforced composites fall in the 4–6 range. Whisker-reinforced and fibre-reinforced composites have a toughness in the 8–10 and 10–25 range, respectively. Transformation-toughened ceramics fall in the 6–15 range. At such toughness large TTZ ball bearings can be repeatedly bounced on concrete floors without noticeable surface damage. (Thomas O. Mason, 2011)

2.1.3 Thermal and physical properties

2.1.3.1 Density

Density, or more precisely, the volumetric mass density, of a substance is its mass per unit volume. The symbol most often used for density is ρ (the lower-case Greek letter rho), although the Latin letter D can also be used. Mathematically, density is defined as mass divided by volume (The National Aeronautic and Atmospheric Administration's Glenn Research Center, 2013)



where ρ is the density, m is the mass, and V is the volume. In some cases (for instance, in the United States oil and gas industry), density is loosely defined as its weight per unit volume, (Oil Gas Glossary, 2010) although this is scientifically inaccurate – this quantity is more specifically called specific weight. An example of density is stated in (figure 2.6)and (figure 2.7).

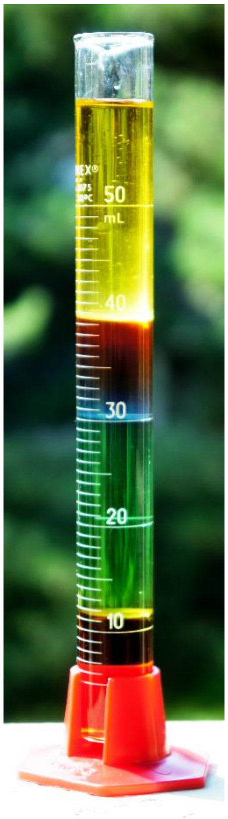


Figure 2.4 cylinder with colored fluids with different densities

Figure 2.5 comparison between the density of fluids and solids

For a pure substance the density has the same numerical value as its mass concentration. Different materials usually have different densities, and density may be relevant to buoyancy, purity and packaging. Osmium and iridium are the densest known elements at standard conditions for temperature and pressure but certain chemical compounds may be denser.

To simplify comparisons of density across different systems of units, it is sometimes replaced by the dimensionless quantity "relative density" or "specific gravity", i.e. the ratio of the density of the material to that of a standard material, usually water. Thus, a relative density less than one means that the substance floats in water.

The density of a material varies with temperature and pressure. This variation is typically small for solids and liquids but much greater for gases. Increasing the pressure on an object decreases the volume of the object and thus increases its density. Increasing the temperature of a substance (with a few exceptions) decreases its density by increasing its volume. In most materials, heating the bottom of a fluid results in convection of the heat from the bottom to the top, due to the decrease in the density of the heated fluid. This causes it to rise relative to more dense unheated material.

The reciprocal of the density of a substance is occasionally called its specific volume, a term sometimes used in thermodynamics. Density is an intensive property in that increasing the amount of a substance does not increase its density; rather it increases its mass.

2.2 Material selection methods

2.2.1 Cost vs performance

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. Such a cost vs performance index can be used for optimizing the selection of a material. However, the cost of a material expressed in price / 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 emphasize 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 and maintenance costs. One of the methods within cost vs performance is the Cost per unit property method, this method is suitable for initial screening in situation where one property stands out as the most critical service requirement. In this case, it is possible to estimate how much various materials to provide this requirement will cost. Cost / unit tensile ($$/ MPa) strength is usually one of the most important criteria. Limitations of this method is that it considers only one property as the most critical and ignoring other properties, the second method of cost vs performance is the Weighted Property Method, In most applications, the selected material should satisfy more than one functional requirement. In this method each material requirement (or property) is assigned a certain weight (which depends on its importance to the performance of the design) This method attempts to quantify how important each desired requirement is by determining a weighting factor (α) and quantify how well a candidate material satisfies each requirement by determining a scaling factor (β) as shown figure(2.6) (Ali Ourdjini 2005)

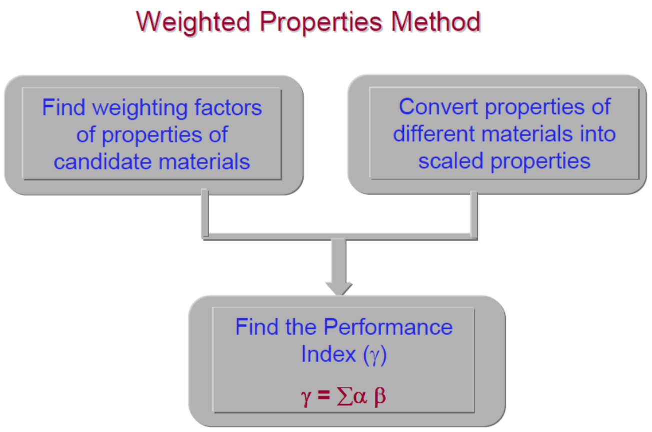


Figure 2.6 Weighted properties method

2.2.2 Failure analysis

Analyzing failures is a critical process in determining the physical root causes of problems. The process is complex, draws upon many different technical disciplines, and uses a variety of observation, inspection, and laboratory techniques. One of the key fac-tors in properly performing a failure analysis is keeping an open mind while examining and analyzing the evidence to foster a clear, unbiased perspective of the failure. Just as failure analysis is a proven discipline for identifying the physical roots of failures, root-cause analysis (RCA) techniques are effective in exploring some of the other contributors to failures, such as the human and latent root causes. Properly performed, failure analysis and RCA are critical steps in the overall problem-solving process and are key ingredients for correcting and preventing failures, achieving higher levels of quality and reliability.

A logical failure analysis approach first requires a clear understanding of the failure definition and the distinction between an indicator (i.e., symptom), a cause, a failure mechanism, and a consequence. A clear understanding of each piece of the situation associated with a failure greatly enhances the ability to under-stand causes and mitigating options and to specify appropriate corrective action.

The FMEA (The Failure Mode and Effect Analysis) methodology is based on a hierarchical, inductive approach to analysis; the analyst must determine how every possible failure mode of every system component affects the system operation. The procedure consists of:

1. Identify all item failure modes

2. Determine the effect of the failure for each failure mode, both locally and on the overall system being analyzed

3. Classify the failure by its effects on the system operation and mission

4. Determine the failure probability of occurrence

5. Identify how the failure mode can be detected

6. Identify any compensating provisions or design changes to mitigate the failure effects (ASM Handbook 2002)

2.2.3 Value analysis

Value analysis is an organized system of techniques for identifying and removing unnecessary costs without compromising the quality and reliability of the product. Its greatest potential is when used earlier in the process before design details have been set. Value analysis is a team-problem solving process designed to optimize the value of a product. It involves breaking a product down into its component parts and determining the value of these design elements relative to the importance of the functions which they provide. Success of value analysis depends on understanding the relationships between each design feature of a component and its function. Value is given as worth of a feature or component / cost. There are two types of values, either Use values which are related to the characteristics (properties) that accomplish a use, work or service (FUNCTION) or Esteem values which are related to the characteristics that make the consumer want to buy the product. This type of values includes appearance, reliability, durability and ease of servicing or maintenance. A three step approach is used in value analysis; Identifying the primary and secondary functions, identifying the monetary value for each function and developing value alternatives. (Ali Ourdjini 2005)

2.2.4 Benefit -cost ratio

BCA compares alternative ways of meeting a specific objective. It analyses and compares costs, benefits and uncertainties to determine the most cost effective and beneficial means to satisfy the objective. This method is used when economic resources are constrained and Comparisons are made on the basis of Benefit-Cost Ratio (BCR)

$$\text{BCR} = (\text{benefit} - \text{disbenefits}) / \text{cost}$$

BCR is an indication of the price paid for improvements. The benefits expressed in monetary value include any improvement in material property or performance, etc., Benefits include all advantages minus any disadvantages (if any). The cost means all costs (material, fabrication, construction, operation, maintenance) less any savings (savings are not benefits but reduction in cost) A project is considered viable when the net benefits associated with its implementation exceed its associated costs This method is most commonly used by governmental agencies for determining the desirability of public works projects. A design with a BCR < 1 is not viable and A design with BCR > 1 is acceptable. When using the benefit-cost analysis to select amongst many alternatives, the best solution can be selected by applying the principles of incremental return. (Ali Ourdjini 2005)

2.3 UTVA 75 Aircraft

2.3.1 History

The UTVA 75 is a compact, low-wing monoplane, piston-engine aircraft manufactured by UTVA. It was mainly used as a military basic trainer and sporting aircraft. Designed in 1975 to replace the UTVA Aero 3 as the primary basic trainer in the Yugoslav Air Force. It features upward opening gull-wing type access doors to the two-seat side-by-side cockpit. Another characteristic is a row of air scoops, presumably for cockpit ventilation, in the central front frame of the cockpit. (Dusan 2018)

The Utva 75 made its maiden flight in 1976. Between 1979 and 1985, a total of 136 Utva 75s were produced for the former Yugoslav Air Force.

Figure 2.7 UTVA 75 Aircraft

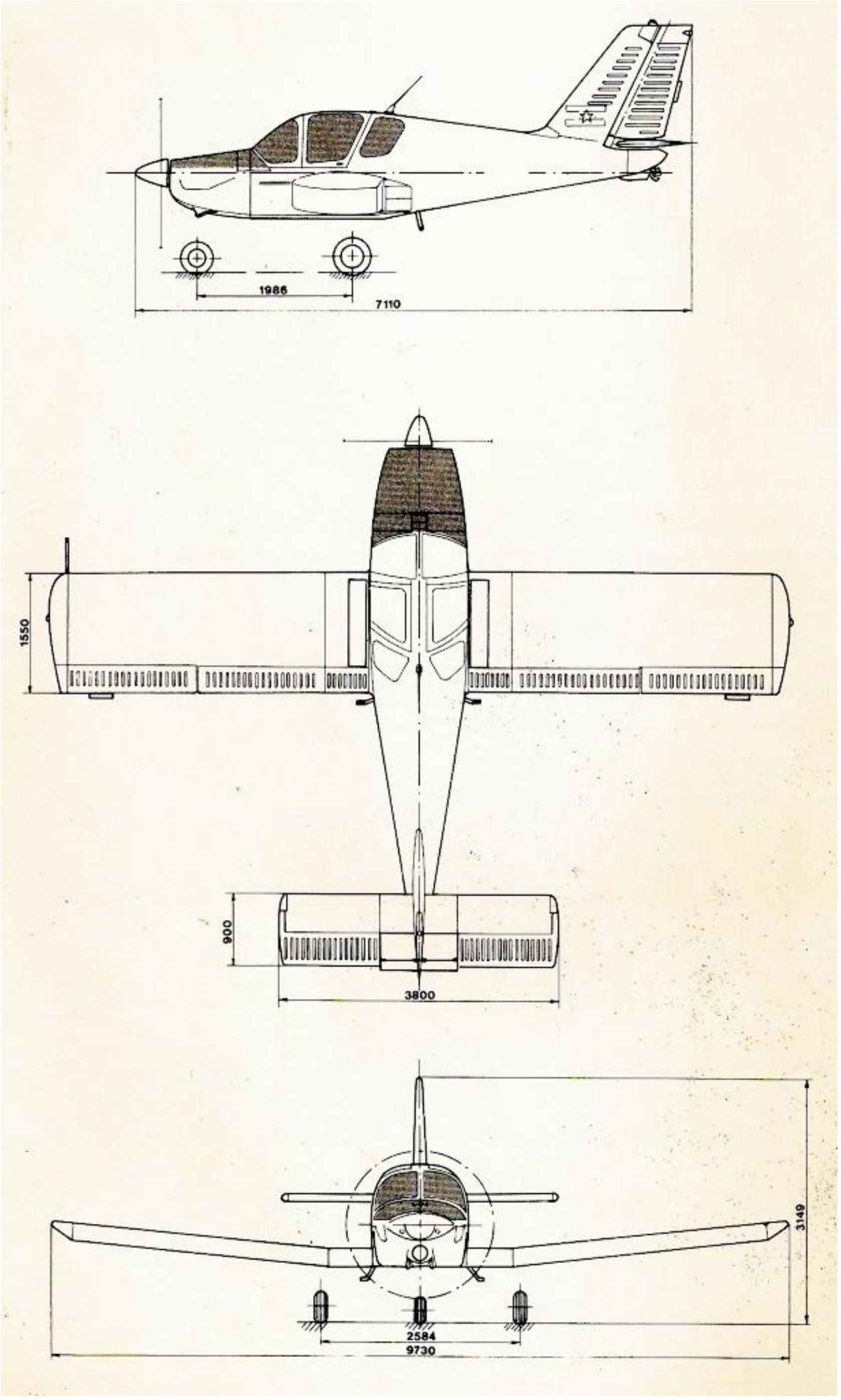


Figure 2.8 views of UTVA 75 aircraft

2.3.2 Specifications

(John W.R. Taylor, ed. (1988)

General characteristics	
Crew	2
Capacity	210 kg (460 lb) max
Length	7.11 m (23 ft 4 in)
Wingspan	9.73 m (31 ft 11 in)
Height	3.15 m (10 ft 4 in)
Wing area	14.63 m2 (157.5 sq ft)
Aspect ratio	6.5
Empty weight	685 kg (1,510 lb) equipped
Max takeoff weight	960 kg (2,116 lb)
Fuel capacity	standard:160 l (42 US gal; 35 imp gal): with drop tanks 360 l (95 US gal; 79 imp gal)
Powerplant	1 × Lycoming IO-360-B1F 4-cyl. air-cooled horizontally-opposed piston engine, 134 kW (180 hp)
Propellers	2-bladed Hartzell HC-C2YK-1BF/F7666A variable-pitch metal propeller
Performance	
Maximum speed	215 km/h (134 mph; 116 kn)
Cruise speed	165 km/h (103 mph; 89 kn)
Stall speed	95 km/h (59 mph; 51 kn) flaps up at idle 82 km/h (51 mph; 44 kn) 25° flap at idle
Range	800 km (497 mi; 432 nmi)
Ferry range	1,080 km (671 mi; 583 nmi)
Service ceiling	4,000 m (13,000 ft)
g limits	+4.4 -2.2
Rate of climb	4.5 m/s (890 ft/min)
Maximum speed	215 km/h (134 mph; 116 kn)
Cruise speed	165 km/h (103 mph; 89 kn)
Stall speed	95 km/h (59 mph; 51 kn) flaps up at idle 82 km/h (51 mph; 44 kn) 25° flap at idle
Range	800 km (497 mi; 432 nmi)
Ferry range	1,080 km (671 mi; 583 nmi)
Service ceiling	4,000 m (13,000 ft)
Avionics	
Radio	optional King KY 195B radio with standard radio compass

Table 2.1 Specifications of UTVA 75 aircraft

2.3.3 Lycoming engine

The Lycoming O-360 series engines are four-cylinder, direct-drive, horizontally opposed, air-cooled models. The cylinders are of conventional air-cooled construction with heads made from an aluminum-alloy casting and a fully machined combustion chamber. Rocker-shaft bearing supports are cast integral with the head, along with housings to form the rocker boxes. The cylinder barrels have deep integral cooling fins, and the inside of the barrels are ground and honed to a specified finish. The IO-360 and TIO-360 series engines are equipped with a fuel-injection system, which schedules fuel flow in proportion to airflow. Fuel vaporization takes place at the intake ports.(Lycoming 2004)

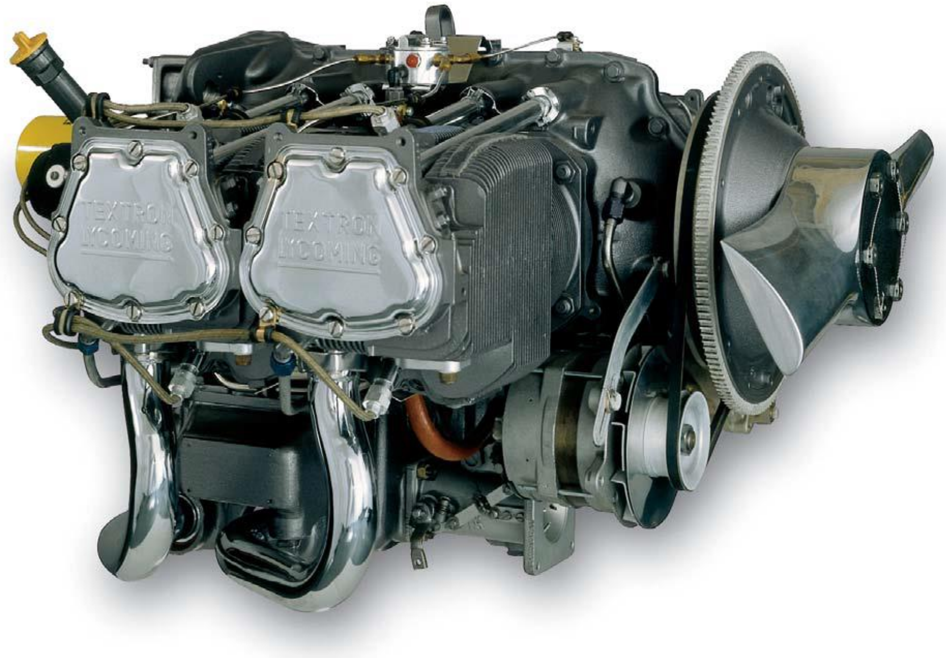


Figure 2.9 Lycoming IO 360 engine

The cylinders are of conventional air-cooled construction with the two major parts, head and barrel, screwed and shrunk together. The heads are made from an aluminum alloy casting with a fully machined combustion chamber. Rocker shaft bearing supports are cast integral with the head along with housings to form the rocker boxes. The cylinder barrels have deep integral cooling fins and the inside of the barrels are ground and honed to a specified finish.

For maximum service life, cylinder head temperatures should be maintained below 435°F (224°C) during high performance cruise operation and below 400°F (205°C) for economy cruise powers. (Lycoming 2009)

2.3.4 Utva 75 exhaust

The construction of the Utva 75 exhaust system contains many parts as shown in figure 2.10 and figure 2.11. The exhaust system not only expels engine gases but also provides cabin heating though heat exchange between the exterior of the exhaust pipe and the air entering the cabin.

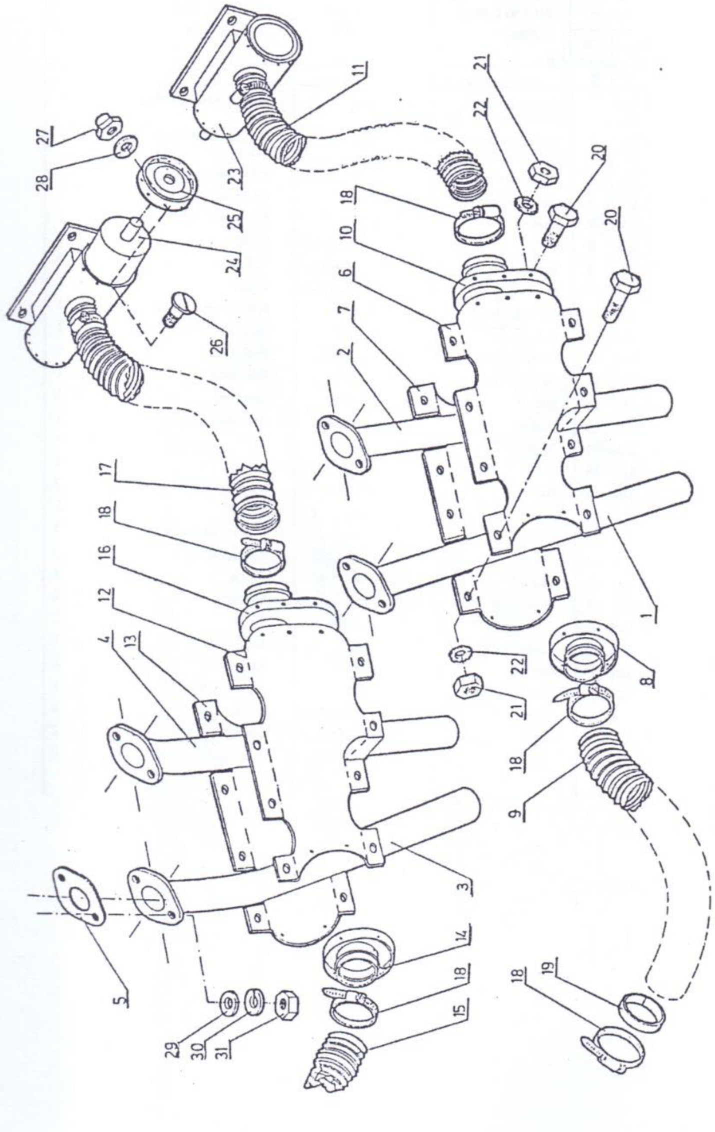
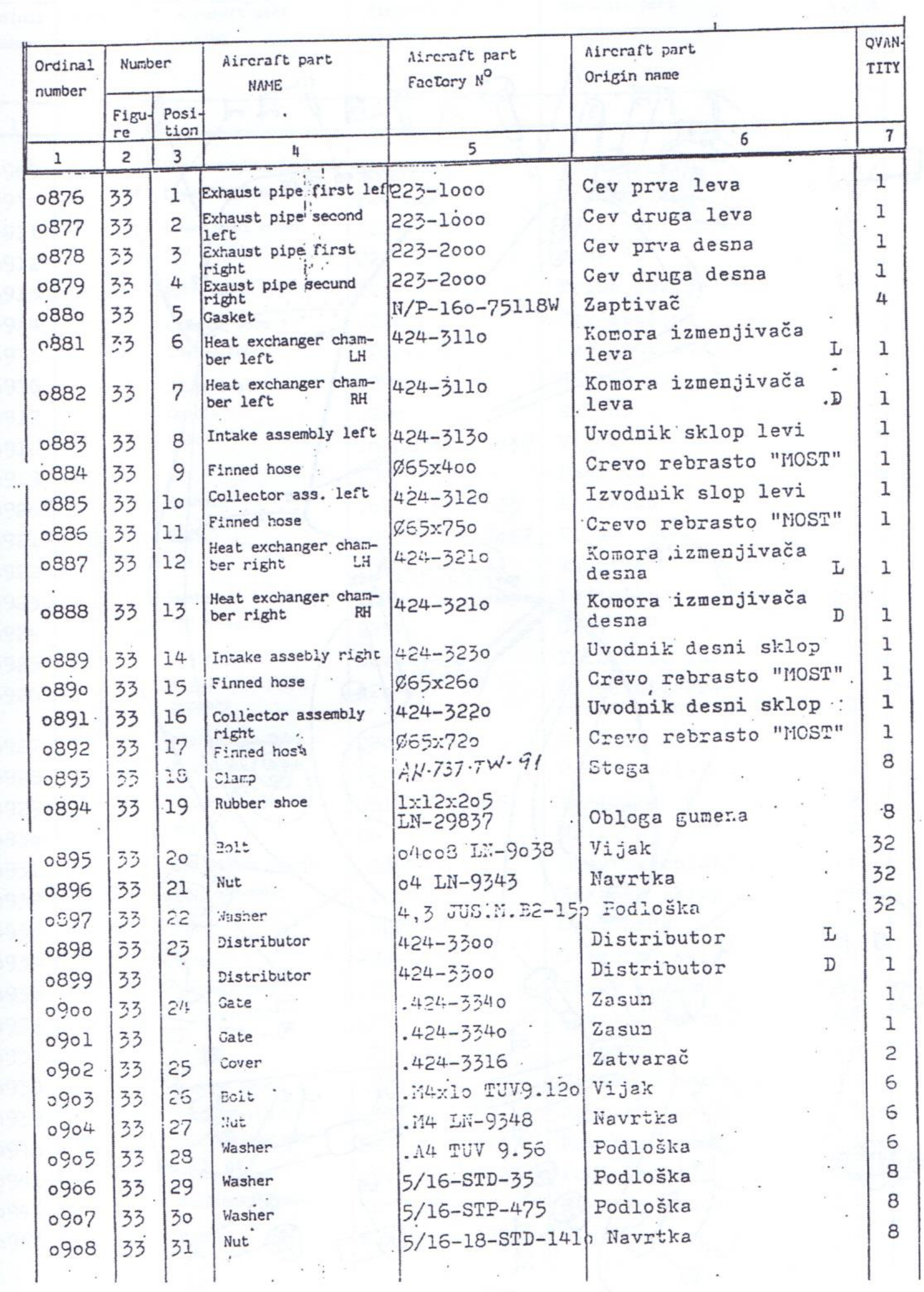


FIGURE 33. EXHAUST PIPES AND HEAT EXCHANGERS ASSEMBLY

Figure 2.10 exploded view of Utva 75 standard exhaust from Utva 75 parts catalog



Ordinal number	Number		Aircraft part NAME	Aircraft part Factory N°	Aircraft part Origin name	QVANTITY
	Figure	Position				
1	2	3	4	5	6	7
o876	33	1	Exhaust pipe first lef	223-1ooo	Cev prva leva	1
o877	33	2	Exhaust pipe second left	223-1ooo	Cev druga leva	1
o878	33	3	Exhaust pipe first right	223-2ooo	Cev prva desna	1
o879	33	4	Exaust pipe secund right	223-2ooo	Cev druga desna	1
o88o	33	5	Gasket	N/P-16o-75118W	Zaptivač	4
o881	33	6	Heat exchanger chamber left LH	424-311o	Komora izmenjivača leva L	1
o882	33	7	Heat exchanger chamber left RH	424-311o	Komora izmenjivača leva D	1
o883	33	8	Intake assembly left	424-313o	Uvodnik sklop levi	1
o884	33	9	Finned hose	Ø65x4oo	Crevo rebrasto "MOST"	1
o885	33	1o	Collector ass. left	424-312o	Izvodnik slop levi	1
o886	33	11	Finned hose	Ø65x75o	Crevo rebrasto "MOST"	1
o887	33	12	Heat exchanger chamber right LH	424-321o	Komora izmenjivača desna L	1
o888	33	13	Heat exchanger chamber right RH	424-321o	Komora izmenjivača desna D	1
o889	33	14	Intake assebly right	424-323o	Uvodnik desni sklop	1
o89o	33	15	Finned hose	Ø65x26o	Crevo rebrasto "MOST"	1
o891	33	16	Collector assembly right	424-322o	Uvodnik desni sklop	1
o892	33	17	Finned hose	Ø65x72o	Crevo rebrasto "MOST"	1
o893	33	18	Clamp	AN-737-TW-91	Stega	8
o894	33	19	Rubber shoe	1x12x2o5 LN-29837	Obloga gumena	8
o895	33	2o	Bolt	o4co8 LN-9o38	Vijak	32
o896	33	21	Nut	o4 LN-9343	Navrtka	32
o897	33	22	Washer	4,3 JUS.M.B2-15o	Podloška	32
o898	33	23	Distributor	424-33oo	Distributor L	1
o899	33		Distributor	424-33oo	Distributor D	1
o9oo	33	24	Gate	424-334o	Zasun	1
o9o1	33		Gate	424-334o	Zasun	1
o9o2	33	25	Cover	424-3316	Zatvarač	2
o9o3	33	26	Bolt	M4x1o TUV9.12o	Vijak	6
o9o4	33	27	Nut	M4 LN-9348	Navrtka	6
o9o5	33	28	Washer	A4 TUV 9.56	Podloška	6
o9o6	33	29	Washer	5/16-STD-35	Podloška	8
o9o7	33	3o	Washer	5/16-STP-475	Podloška	8
o9o8	33	31	Nut	5/16-18-STD-141o	Navrtka	8

Figure 2.11 components of Utva 75 exhaust from Utva 75 parts catalog

CHAPTER III

METHOD

3.1 Identifying material selection method

In general, many methods are available to conduct material selection, but according to the research proposal the approach that will be used must have some unique characteristics:

- It must use a systematic approach to ensure the repeatability of results
- The method should incorporate a material database where selection is made
- It must have a ranking method, as material sometimes can withstand loads but have high cost therefore making it unfit for selection
- It must be based on the mechanical properties of materials, making the selection process scientific rather than being opinion based.

A table was made incorporating these criteria:

	Cost vs performance	Failure analysis	Value analysis	Ashby's method	Benefit cost analysis
systematic approach	✓	✓	✓	✓	✓
material database				✓	
ranking method				✓	
based on the mechanical properties				✓	

Table 3.1 criteria versus selection method

From table 3.1 , we conclude that the Ashby's method will the best material selection method to solve our problem.

3.2 Material Selection method

The manner in which the selection process was conducted followed steps indicated below, the method implies a systematic process from design perspective of material selection.

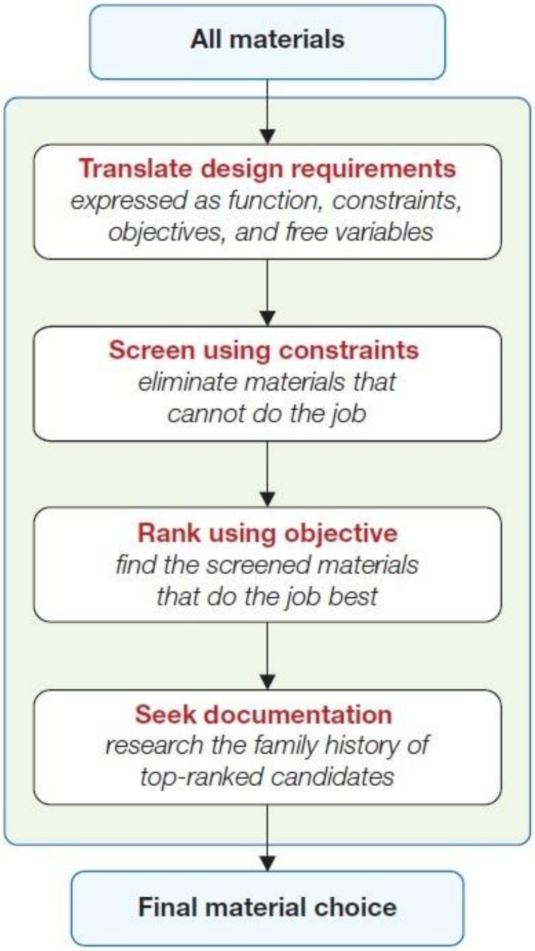


Figure 3.1 Material selection strategy (Ashby 2007e)

3.2.1 Translation

The breakdown of translation step is shown in table 3.2,

Translation steps	
1	Define the design requirements: *Function:* What does the component do*?* *Constraints:* Essential requirements that must be met: e.g., stiffness, strength, corrosion resistance, forming characteristics, etc. *Objective:* What is to be maximized or minimized? *Free variables:* Which are the unconstrained variables of the problem?
2	List the constraints (no yield, no fracture, no buckling, etc.) and develop an equation for them if necessary.
3	Develop an equation for the objective in terms of the functional requirements, the geometry, and the material properties (*objective function*).
4	Identify the free (unspecified) variables.
5	Substitute the free variables from the constraint equations into the objective function.
6	Group the variables into three groups: functional requirements F, geometry G, and material properties M; thus Performance metric $P \geq f1(F) \cdot f2(G) \cdot f3(M)$ or performance metric $P \leq f1(F) \cdot f2(G) \cdot f3(M)$
7	Read off the material index, expressed as a quantity M that optimizes the performance metric P. M is the criterion of excellence.

Table 3.2 Translation step elaboration (Ashby 2007f)

Design requirements
A material is required for an UTVA 75 engine exhaust pipe to expel gases while holding structural integrity In order to hold structural integrity and not fracture, the exhaust pipe must not fail (fracture) due to stresses and have a service temperature higher than that of engine gases and connecting body, have high corrosion resistance and must be lightweight, the cheapest material that satisfies the above criteria shall be selected.

Table 3.3 Design requirements statement (Ashby 2007g)

Design requirements	**Definition**	**Acquired design requirements**
Function	What does the component do?	Exhaust pipe for aircraft
Constraints	What nonnegotiable conditions must be met? What negotiable but desirable conditions must be met?	1. Service temperature to be above 336°C * 2. Fracture toughness not less than 27 Mpa.$m^{0.5}$ **
Objective	What is to be maximized or minimized?	Fracture toughness and density to be maximized
Free variable	Which parameters of the problem is the designer free to change?	Length of pipe
* According to Lycoming engine data sheet the maximum cylinder head temperature (CHT) = 224°C (Lycoming 2004), adding to it the standard aerospace factor of safety (FoS) for structures (1.5), the minimum service temperature would be 336°C ** For fracture toughness, it is quoted that the minimum value for conventional design is 18 Mpa.$m^{0.5}$ (Ashby 2011). adding to it the standard aerospace factor of safety (FoS) for structures (1.5), the minimum fracture toughness should be 27 Mpa.$m^{0.5}$.		

Table 3.4 translation breakdown

To calculate the material index:

First, an equation is identified for fracture toughness

$$k_{1c} = \sigma(\pi c)^{0.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$\sigma \geq \frac{F*}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

The failure strength should be more than the force over area that will cause fracture,

$$k_{1c} = \frac{F}{A}(\pi c)^{0.5} \ \ldots\ldots\ldots\ldots\ldots\ldots\text{...from (1) and (2)}$$

$$A = \frac{F}{k_{1c}}(\pi c)^{0.5}$$

then an equation for mass is identified, where the variable A is included:

$$m = Al\rho$$

Substituting the mass into the equation:

$$m = \frac{F}{k_{1c}}(\pi c)^{0.5}\, l\rho$$

substituting the equation into the form of a performance metric

$$(P \geq f1(F) \cdot f2(G) \cdot f3(M))$$

$$m \ \geq F * (\pi c)^{0.5} l * \left(\frac{\rho}{k_{1c}}\right)$$

And because what is required is the reduction of mass:

$$m \ \leq F * (\pi c)^{0.5} l * \left(\frac{k_{1c}}{\rho}\right)$$

The next step would be to check the material property charts with the includes both density and fracture toughness, putting in mind the maximum service temperature. This is the screening process.

3.2.2 Screening

The screening step in material selection is done to eliminate the materials that cannot function or the perform the required job. Therefore, in the case of this study screening indicates which material cannot operate with the specified service temperature and has a fracture toughness below the required range. Chart used to indicate the service temperature is (figure 3.2) while fracture toughness shall be observed from the tables in (figure 3.3,3.4)

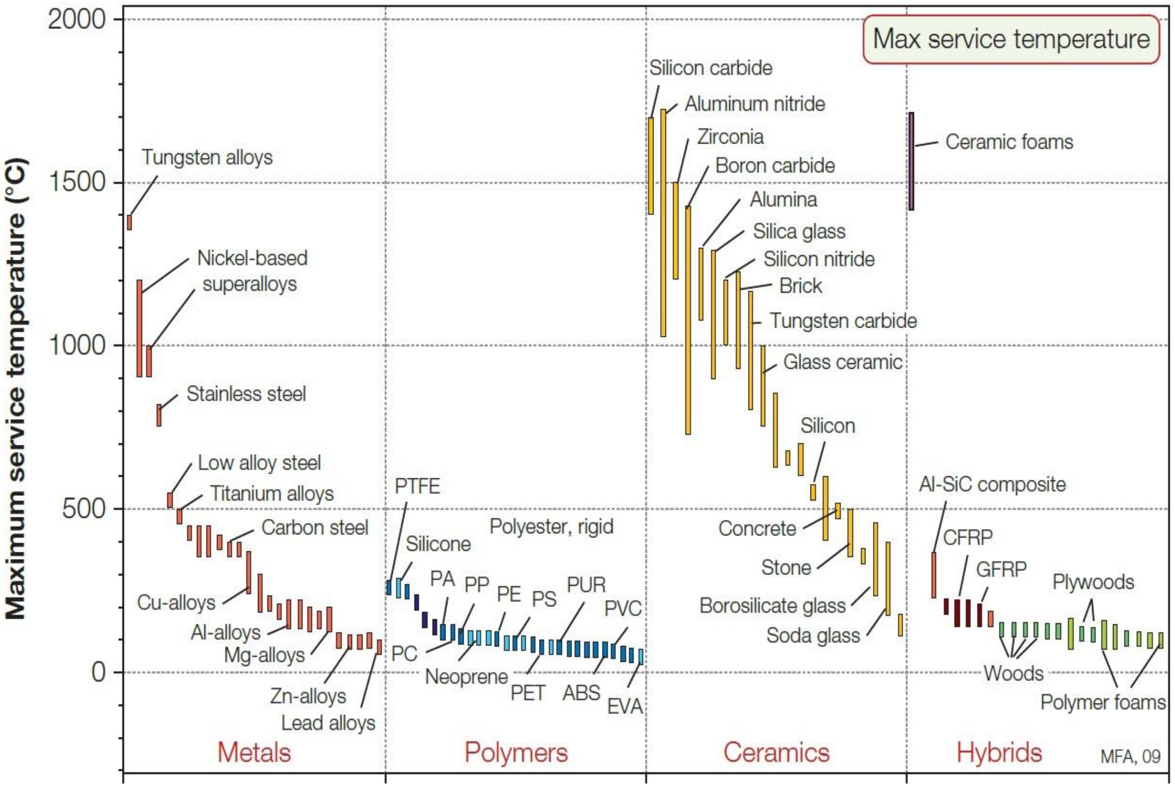
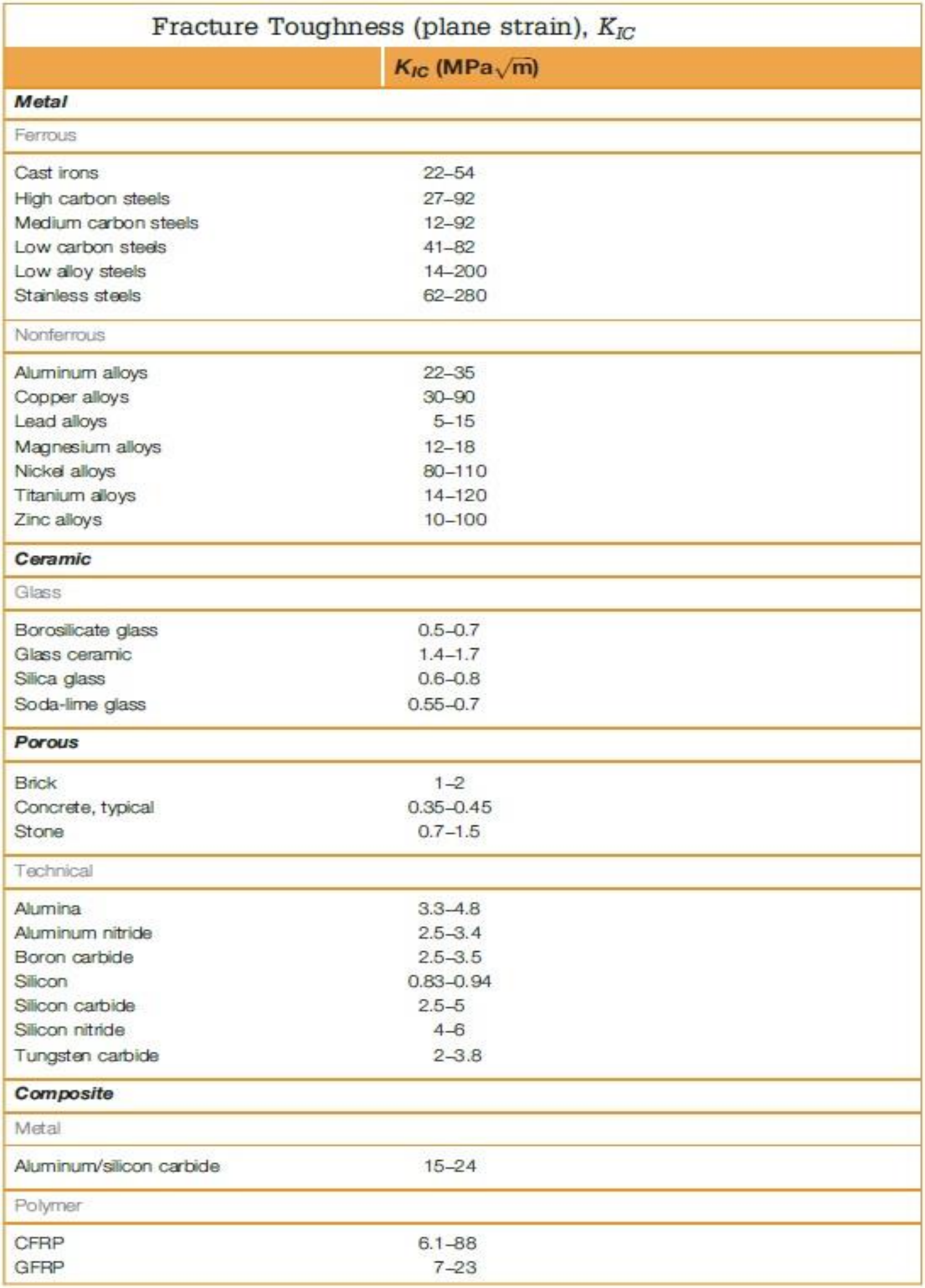


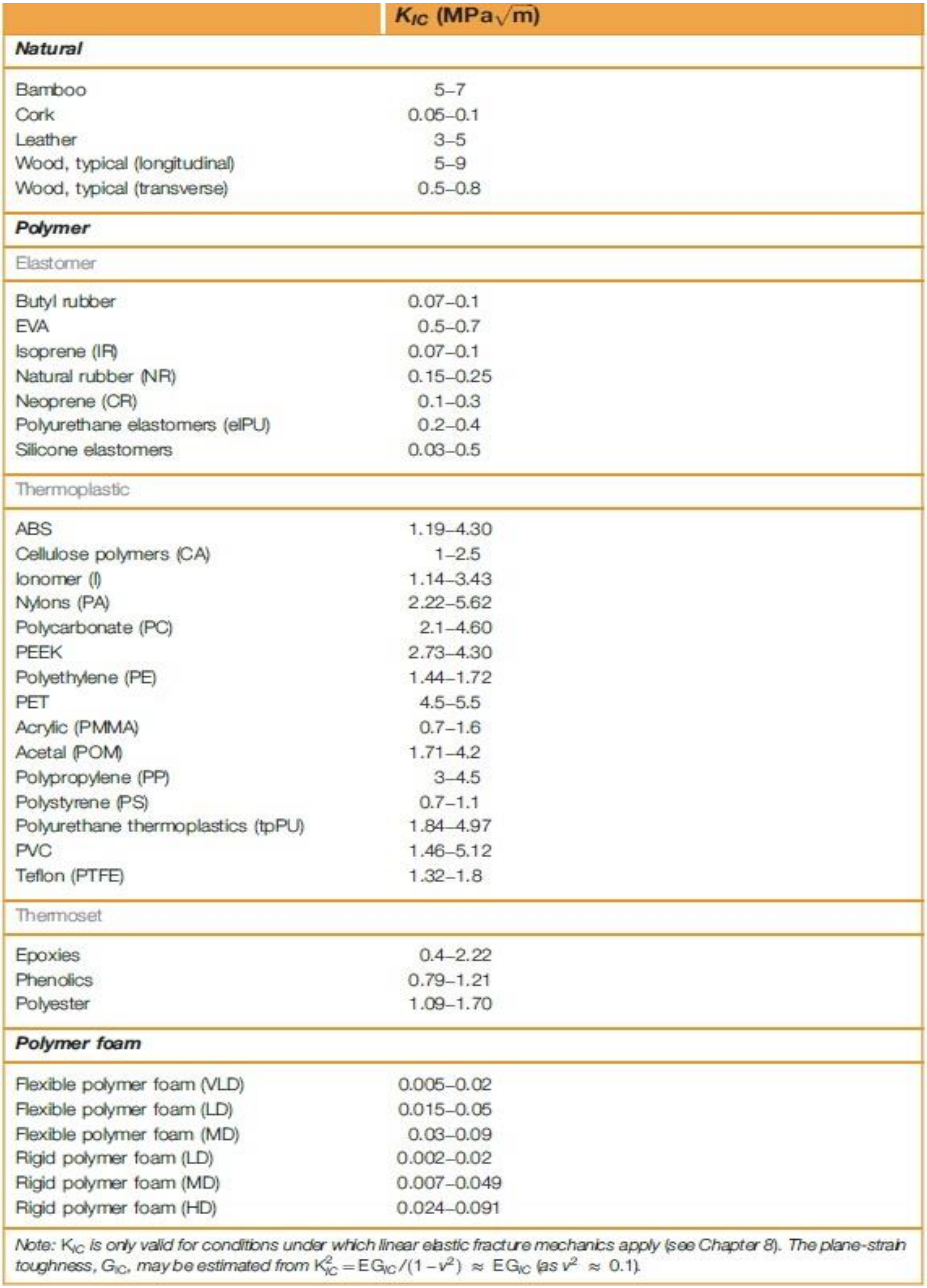
Figure 3.2 maximum service temperature chart (Ashby 2007h)



Fracture Toughness (plane strain), K_{IC}

	K_{IC} ($\mathrm{MPa}\sqrt{\mathrm{m}}$)
Metal	
Ferrous	
Cast irons	22–54
High carbon steels	27–92
Medium carbon steels	12–92
Low carbon steels	41–82
Low alloy steels	14–200
Stainless steels	62–280
Nonferrous	
Aluminum alloys	22–35
Copper alloys	30–90
Lead alloys	5–15
Magnesium alloys	12–18
Nickel alloys	80–110
Titanium alloys	14–120
Zinc alloys	10–100
Ceramic	
Glass	
Borosilicate glass	0.5–0.7
Glass ceramic	1.4–1.7
Silica glass	0.6–0.8
Soda-lime glass	0.55–0.7
Porous	
Brick	1–2
Concrete, typical	0.35–0.45
Stone	0.7–1.5
Technical	
Alumina	3.3–4.8
Aluminum nitride	2.5–3.4
Boron carbide	2.5–3.5
Silicon	0.83–0.94
Silicon carbide	2.5–5
Silicon nitride	4–6
Tungsten carbide	2–3.8
Composite	
Metal	
Aluminum/silicon carbide	15–24
Polymer	
CFRP	6.1–88
GFRP	7–23

Table 3.5 Fracture toughness values (Ashby 2007I)



	K_{IC} (MPa$\sqrt{m}$)
Natural	
Bamboo	5–7
Cork	0.05–0.1
Leather	3–5
Wood, typical (longitudinal)	5–9
Wood, typical (transverse)	0.5–0.8
Polymer	
Elastomer	
Butyl rubber	0.07–0.1
EVA	0.5–0.7
Isoprene (IR)	0.07–0.1
Natural rubber (NR)	0.15–0.25
Neoprene (CR)	0.1–0.3
Polyurethane elastomers (elPU)	0.2–0.4
Silicone elastomers	0.03–0.5
Thermoplastic	
ABS	1.19–4.30
Cellulose polymers (CA)	1–2.5
Ionomer (I)	1.14–3.43
Nylons (PA)	2.22–5.62
Polycarbonate (PC)	2.1–4.60
PEEK	2.73–4.30
Polyethylene (PE)	1.44–1.72
PET	4.5–5.5
Acrylic (PMMA)	0.7–1.6
Acetal (POM)	1.71–4.2
Polypropylene (PP)	3–4.5
Polystyrene (PS)	0.7–1.1
Polyurethane thermoplastics (tpPU)	1.84–4.97
PVC	1.46–5.12
Teflon (PTFE)	1.32–1.8
Thermoset	
Epoxies	0.4–2.22
Phenolics	0.79–1.21
Polyester	1.09–1.70
Polymer foam	
Flexible polymer foam (VLD)	0.005–0.02
Flexible polymer foam (LD)	0.015–0.05
Flexible polymer foam (MD)	0.03–0.09
Rigid polymer foam (LD)	0.002–0.02
Rigid polymer foam (MD)	0.007–0.049
Rigid polymer foam (HD)	0.024–0.091

Note: K_{IC} is only valid for conditions under which linear elastic fracture mechanics apply (see Chapter 8). The plane-strain toughness, G_{IC}, may be estimated from $K_{IC}^2 = EG_{IC}/(1-\nu^2) \approx EG_{IC}$ (as $\nu^2 \approx 0.1$).

Table 3.6 Fracture toughness values (continued)

3.2.3 Ranking

Using the material index specified in the translation step, we can now plot the values obtained on a material property chart, the results obtained should have the highest fracture toughness and highest density, the chart used will be fracture toughness- density chart as shown in figure 3.5

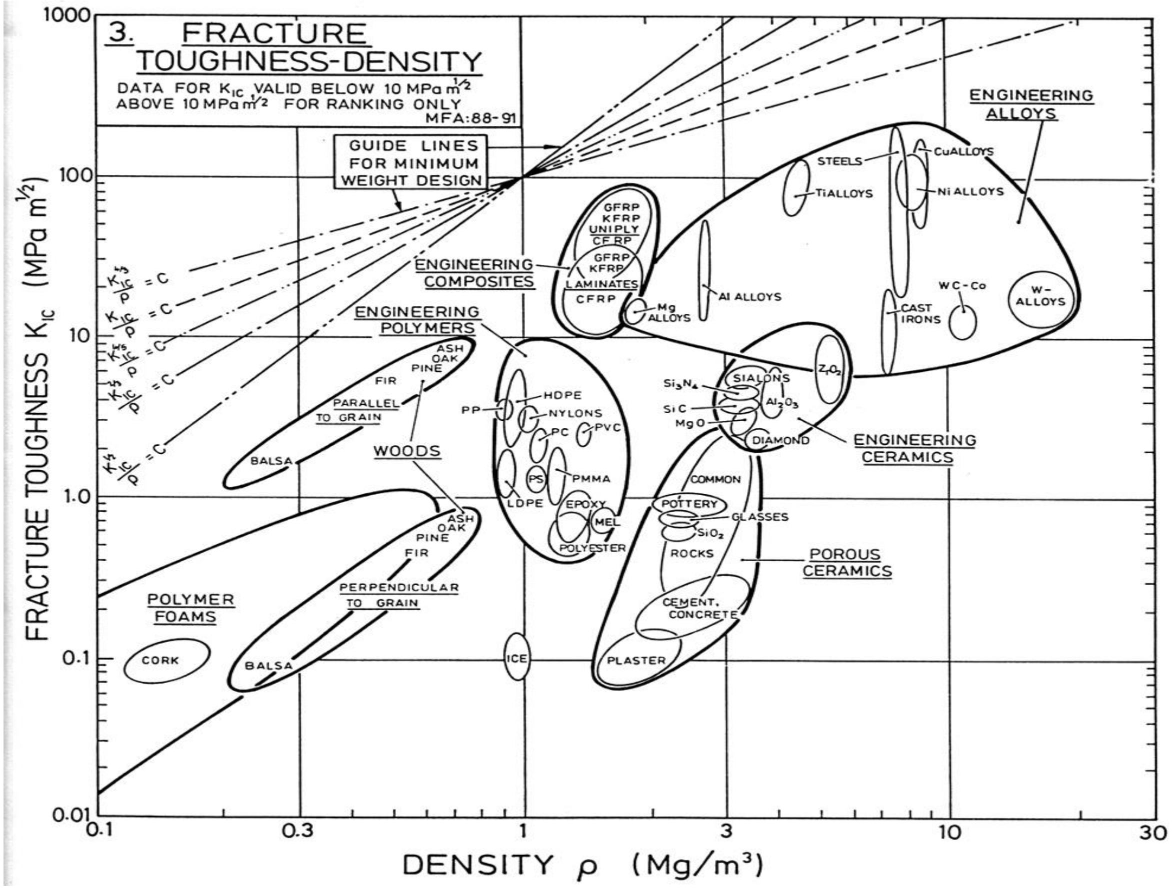


Figure 3.3 fracture toughness -density chart (Ashby 1999)

3.2.4 Documentation

In this step it is more of expert judgement in which we will determine the material which best suits the application needed. In the case it would be best if the material could be cheaper yet have good corrosion properties. Research is conducted beyond general information to find the weaknesses and strengths of each material

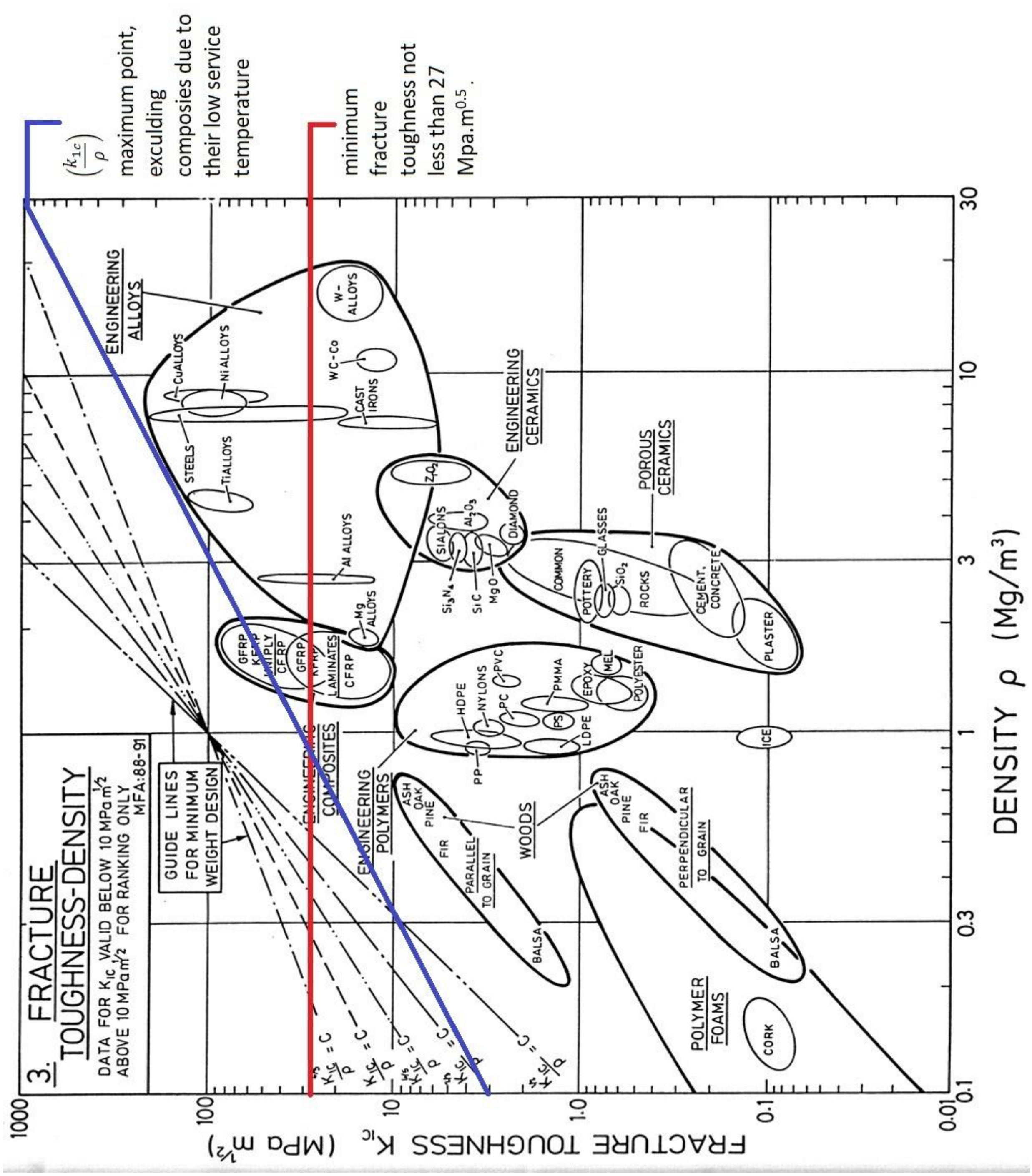
CHAPTER IV

RESULTS

4.1 Results acquirement

Using Figure 3.3 and projecting the data acquired from the table 3.4, the first line was made to indicate the minimum fracture toughness permissible, the material index obtained in chapter three was identified as a diagonal line in the figure 3.3 know as the design guide lines. The line was moved while preserving its slope till it reached the last material group in the graph.

Using figure 3.2 and projecting the data acquired in table 3.4 for maximum service temperature, a line was created to signify the materials that could not be used due to their service temperature allowance.



$\left(\frac{k_{1c}}{\rho}\right)$ maximum point, exculding composies due to their low service temperature

minimum fracture toughness not less than 27 Mpa.m$^{0.5}$.

Figure 4.1 Fracture Toughness-Density Chart with maximum fracture toughness indicated

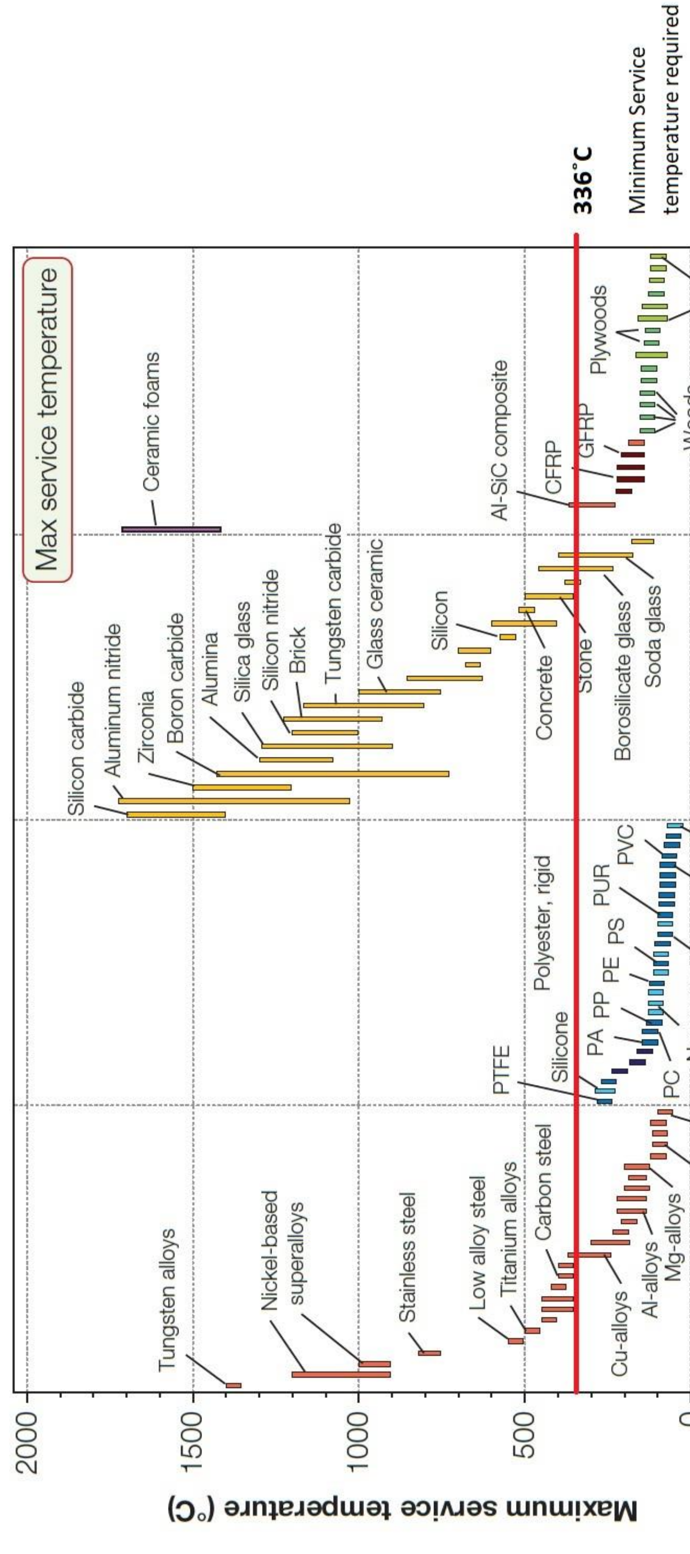


Figure 4.2 permissible service temperature

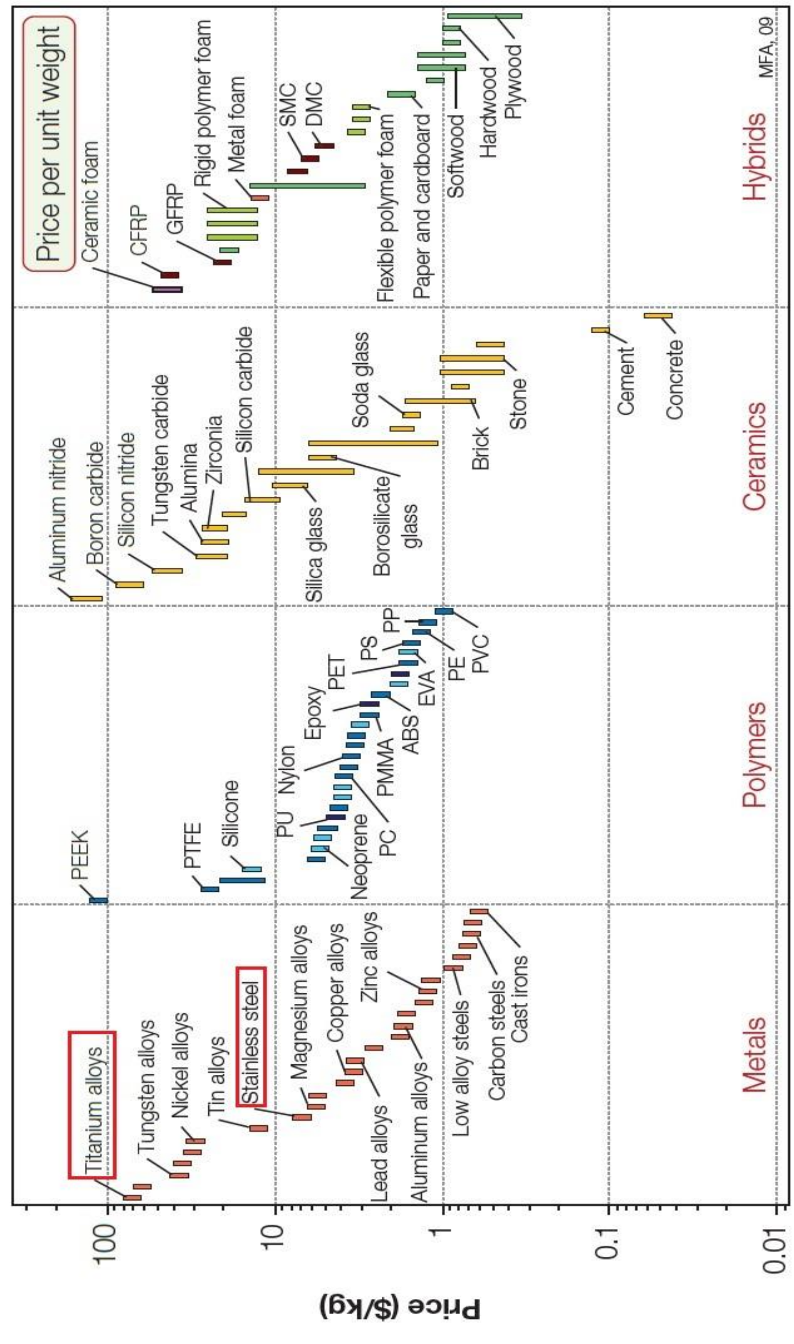


Figure 4.3 price per mass for materials

4.2 Data analysis

It was found from the analysis data done on figure that the material which has the lowest density and highest fracture toughness belongs to the metals group (figure 4.1) after eliminating engineering composites due to the fact that they could not be in service with the required temperature (figure 4.2).

Within the metals group the highest ranking and closest to the indicated line are the family of steels and Titanium alloy. Therefore, these two were the most suitable for the design requirements. For further analysis and to rank which material does the job better in steels family it was determined through identifying which material had the highest fracture toughness (figure 3.3) which was stainless steel.

To determine which of the two materials (stainless-steel or Titanium alloy) better suits our requirements, a review of documentation, according to Michael Ashby’s method, was done (appendix). Both materials had advantages and weaknesses for our application but in terms of cost Titanium alloys surpassed stainless steel therefore stainless steel was selected (figure 4.3).

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 conclusion

From the analysis of data, it was evident that stainless steel was the most suitable material to be used for the aircraft exhaust pipe. The study also concluded that Michael Ashby’s material selection method was suitable for a systematic material selection approach.. Although the last comparison was made between titanium and stainless-steel manufacturers may have also favored stainless steel over titanium due to its price.

In terms of fracture toughness, lightweight and corrosion resistance stainless steel deemed fit to perform the task stated in the design requirements and therefore the new exhaust t pipe will be either manufactured from stainless steel.

5.2 Recommendations

Theoretical experiments must always be coupled with simulation and then actual situation experiments, that is why it is important to conduct live experiments with stainless steel exhausts in the weather of Portsudan and for extended periods. The tests should not only be checking how the new stainless-steel pipes eliminate failure, but also to calculate time saved on maintenance, reduced ground checks for failures, aircraft down time, pilot confidence and spare parts cost. Some of these tests may not be quantitative but they must be tied to a certain quantity in order set a baseline of measure where improvement can rely on in the future if new materials emerge.

As it was evident the selection process was general in terms of specifying the material as stainless steel, but there are numerous types of stainless steel with different usage purposes. Ranging from the common SAE 304 which is cheap and found in hardware store and SAE 316 which used generally for aesthetics purposes, to the tough SAE 321 and many more. It would be scientifically wise to determine exactly which type of stainless-steel can do the job better. To do this it is highly recommended that the Granata material selection software be used, it holds parameters for all types of material and specific types can be selected rather than the general manual method used in this thesis. It should also be noted that the Granata material selection software was developed for use with the Michael Ashby’s material selection method.

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APPENDIX 1

Appendix1

7.1 Comparison of exhaust material by aircraft manufacturers

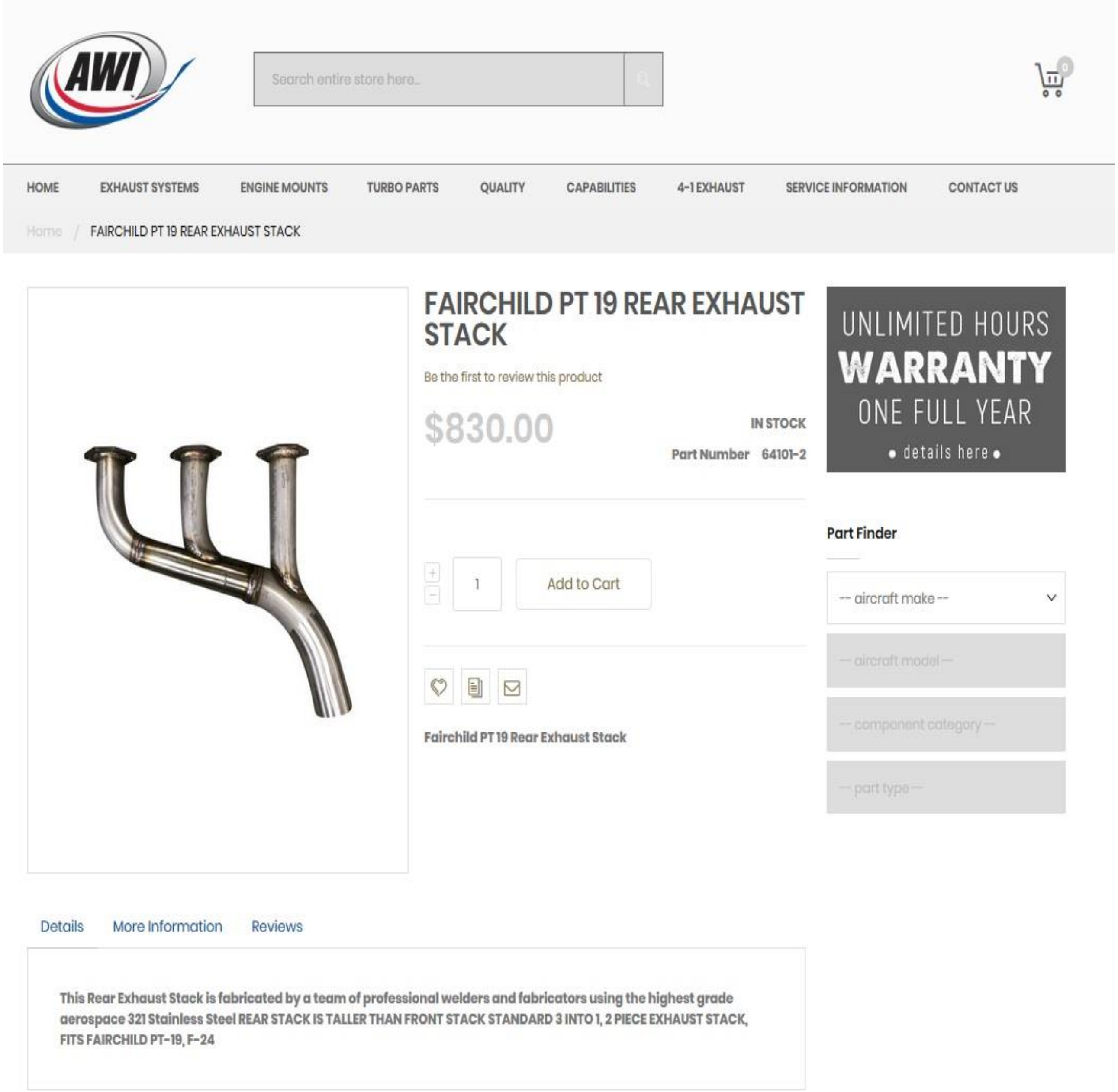

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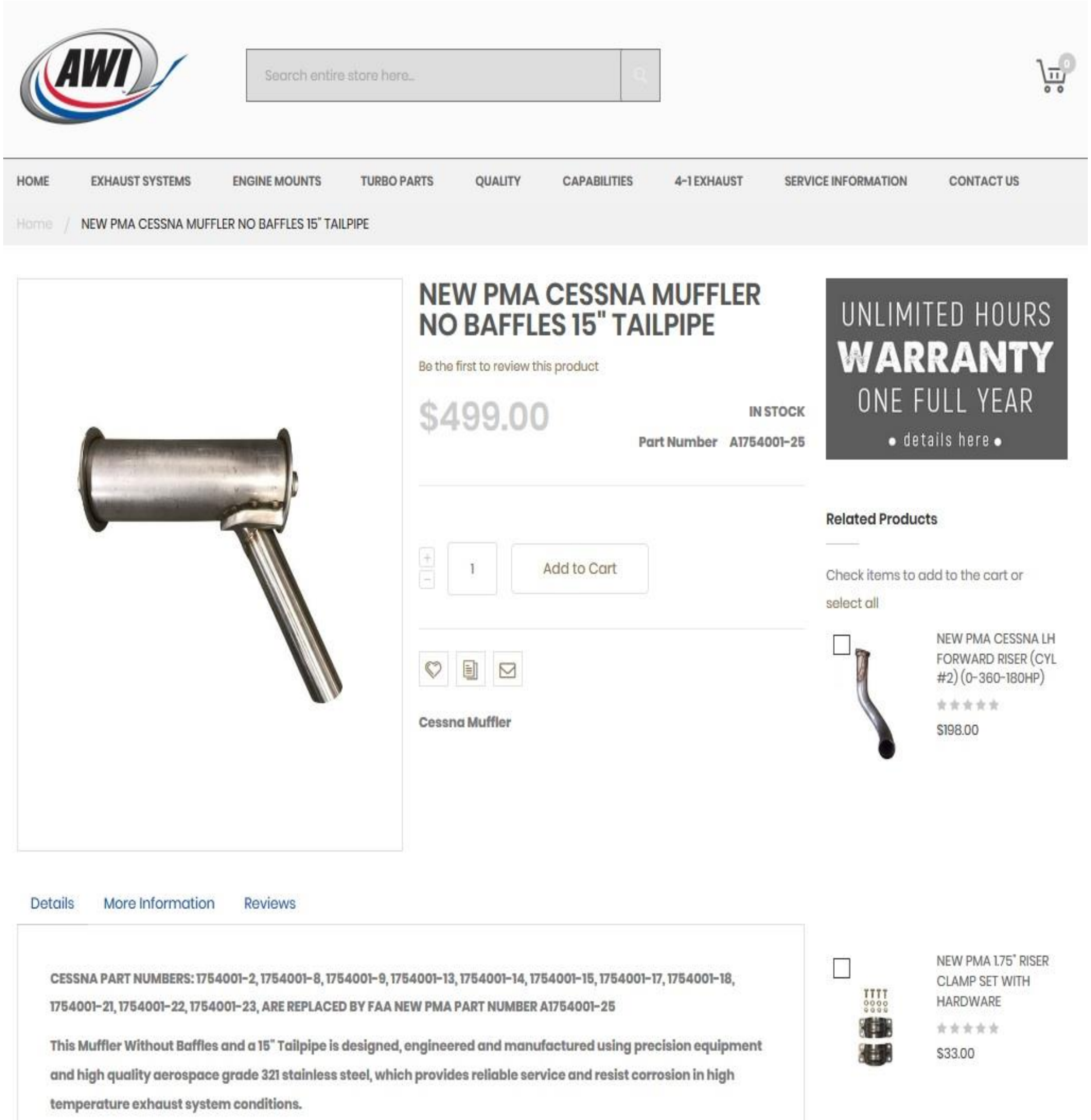
Figure 7.1 Fairchild exhaust from catalog



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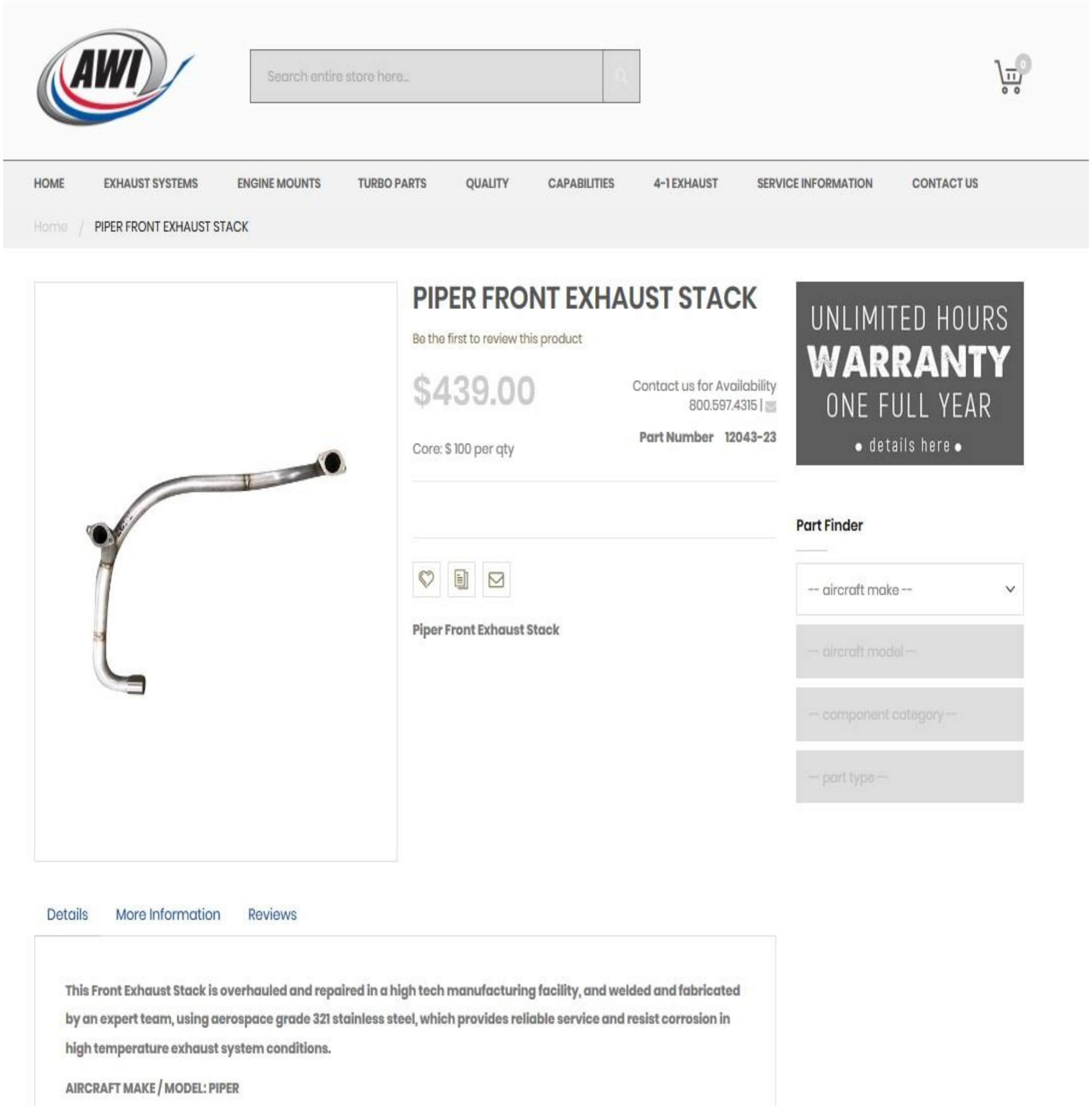
CESSNA PART NUMBERS: 1754001-2, 1754001-8, 1754001-9, 1754001-13, 1754001-14, 1754001-15, 1754001-17, 1754001-18, 1754001-21, 1754001-22, 1754001-23, ARE REPLACED BY FAA NEW PMA PART NUMBER A1754001-25

This Muffler Without Baffles and a 15" Tailpipe is designed, engineered and manufactured using precision equipment and high quality aerospace grade 321 stainless steel, which provides reliable service and resist corrosion in high temperature exhaust system conditions.

Figure 7.2Cessna exhaust from catalog



PIPER FRONT EXHAUST STACK

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$439.00

Contact us for Availability
800.597.4315 |

Part Number 12043-23

Core: $ 100 per qty

Piper Front Exhaust Stack

This Front Exhaust Stack is overhauled and repaired in a high tech manufacturing facility, and welded and fabricated by an expert team, using aerospace grade 321 stainless steel, which provides reliable service and resist corrosion in high temperature exhaust system conditions.

AIRCRAFT MAKE / MODEL: PIPER

Figure 7.3 Piper exhaust from catalog