

Statement: The only materials that can be used in the human body are ones that are chemically inert.

Answer: This statement is wrong.

A material is qualified in chemically inert when it does not react with other elements. This inert behaviour can be explained by the fact that these materials usually have an outer shell filled with electrons and as a consequence are very unlikely to share them and are not able to participate in any chemical reaction. The question here is to know if a material needs to have this particular behaviour in order to be used in the human body.

First of all, as it can be seen on the figure 1, materials are used almost everywhere in the human body. With the progress in medicine and our understanding of the body's functionalities, more different materials can be used for implants, medical devices, drug delivery systems etc.

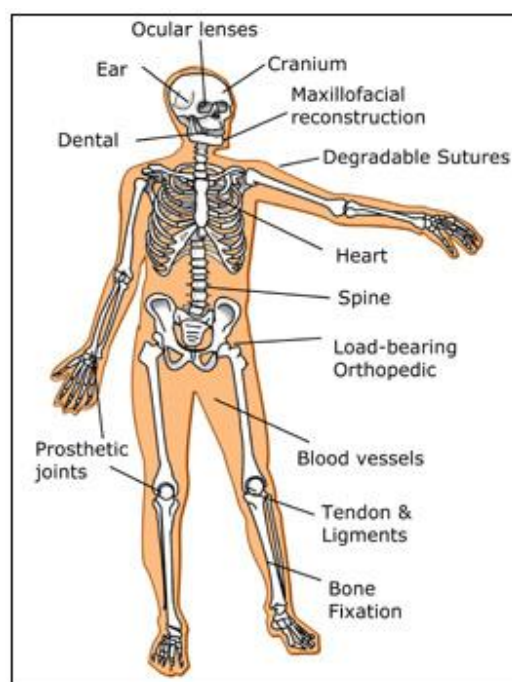


Figure 1: Biomedical applications of materials.¹

These materials are usually selected regarding their mechanical properties. Indeed, optical properties for ocular lenses, strength, stiffness and durability for bone implants are examples among many others. However, because implants are in contact with body fluids, their chemical properties are at least as important as their mechanical properties.

Also, because of the biological response while new materials are introduced in the body must be harmless, they are usually inert which prevents them from oxidation for example. Corrosion influence would be a disaster because effects like pH variations, inflammation, infection, allergic response, bone loss or tumours at implant sites would appear.¹ Considering this the statement would be correct.

¹ <http://ocw.mit.edu/OcwWeb/Materials-Science-and-Engineering/3-051JSpring-2006/CourseHome/>, viewed 12 Nov 2008

Yet, some of the materials or implants in the body are actually not inert. Indeed, theory says that if the impact on human health of the chemical reactions is perfectly controlled and toxicological tests have been properly run, any infection would be avoided. With the advanced done in medicine during the past decades, we are now capable of doing this.

Furthermore, as far as dental implants or hip-joint implants are concerned inert behaviour is no longer possible. Indeed, materials used have to bond to human tissues and this automatically implies chemical reactions: sharing elections for primary bonding (ionic and covalent bonds) but also H bonding and Van der Waals bonding. Good materials for this use would be bioactive ceramics which are wear resistant but also bio compatible.



Figure 2: Hips and dental implants²

Moreover, recent researches³ have shown the possibility of developing bioactive materials assuring physiological functions (tissue engineering). Indeed, instead of directly replacing body tissues, and also because, as the humans life expectancy goes up, implant lifetime of 20 years is now not sufficient, we are now capable of manufacturing very special implants. Their bioactivity is used to activate the body's own repair mechanisms and can for instance simulate genes that activate the proliferation of new cells.

As a conclusion, that considering all what have been said here, it has been proven the statement is wrong. With medicine progress, bioactive materials are now widely used in the human body. It just has to be verified that they will provide the appropriate host response without any infection or allergic response.

² <http://healthbase.wordpress.com/2007/02/06/hip-replacement/>, viewed 12 Nov 2008.

³ Hench L.L, Jones J.R, Sepulveda P, *Bioactive Materials for Tissue Engineering Scaffolds*, chapter 1
http://www.worldscibooks.com/engineering/etextbook/p252/p252_chap1.pdf

Statement: the low density of a carbon fibre reinforced plastic makes it an ideal material for the blade of a helicopter.

Answer: The statement is partially correct.

For the past decades, improvements in aeronautics have been amazing. Indeed, if helicopter blades are considered, they were originally made of wood and fabric. Then, in the 1960s⁴, materials like steel and especially aluminium were introduced. These metal blades were better in every way especially regarding to cost, ease of manufacture but still suffered from design and structural problems because of the material itself. Indeed, metals usually don't have a very good specific strength/stiffness to density ratio; they have also fatigue, creep or corrosion problems... It is going to be discussed here if carbon fibre blades are suitable for helicopter and if they can be the answer to the structural problems that have been mentioned.

First of all concerning basic properties of carbon fibre reinforced plastics, they without a doubt surpass aluminium alloy by far. As a consequence as table 1 shows, if the low density characteristic compared to strength is the only one taken into account it would be possible to build blade 5 times lighter than the metal equivalent.

Table 1: Properties of Carbon fibre reinforced plastic and aluminium alloy⁵

Material	Density ρ (Mg m ⁻³)	young's modulus E(GPa)	Strength σ_y (Mpa)	Fracture toughness K_c (MPa m ^{1/2})	E/ ρ
CFRP 58% uniaxial C in epoxy	1,5	189	1050	35-45	126
Aluminium alloy	2,8	71	500	28	25

Furthermore, fatigue resistance is also an important characteristic and again composite based materials are better than metals. As it can be seen in figure 3 the shape of the S-N curve for an aluminium alloy shows that under stress, life expectancy of the material quickly decrease. Designers are forced to oversize aluminium blades compare to the tensile strength of the material which is obviously bad for the total weight of the structure.

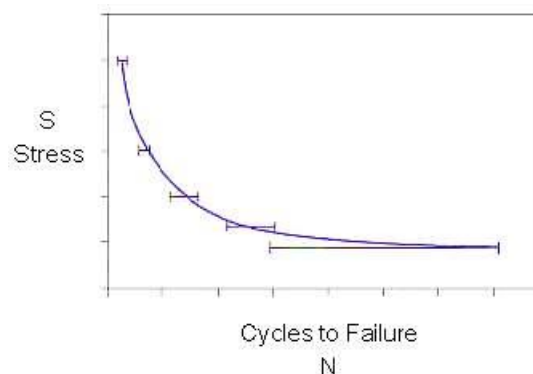


Figure3: Schematic of S-N Curve for an aluminium alloy

⁴ <http://www.whystudymaterials.ac.uk/casestudies/helicopter.asp>

⁵ Ashby, M. F., Jones D. R., (2005), *Engineering Materials 2*, Butterworth Heinemann, p. 293

On the other hand, as figure 4 shows, high modulus carbon fibres do not have that kind of behaviour. Indeed they can support without failure a stress very close to their tensile strength (which is already high) for a long time. This behaviour is great especially for helicopters because the weight that can be gained by designing the blades (regarding the fatigue resistance) is significant.

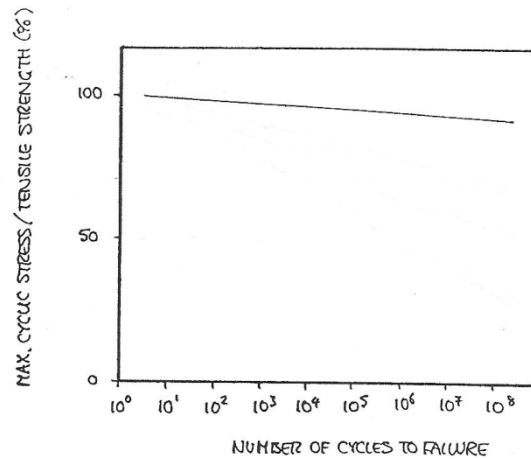


Figure 4: Normalised S-N Curve for a high modulus carbon fibre.⁶

Furthermore, CFRP materials do not have any strength reduction until close to failure. This can be a good point because it means that this property of the blade will remain the same during its whole life. But it has also bad consequences. Indeed, that kind of material has a “sudden-death” behaviour which leads to catastrophic failures and this is unacceptable for a flying mean of transportation. The loss of the entire crew when the blade fails is not affordable. As a consequence, CFRP blades have to be used with caution and it is necessary to monitor them regularly to avoid these catastrophic failures. This can be done via ultrasonic tests for example by analysing the frequency response of the blade (harmonic and nodes move when the material starts to damage).

As a conclusion, the statement is partially correct. It is true that composite materials allow the creation of rotor blades that far surpass their predecessors in many properties but side effects like sudden death process have to be taken into account. That kind of blades are also very expensive to manufacture and that could prevent metallic blade from totally disappearing at least in a near future.

⁶ After Jones et al 1984, Harris 1986

Statement: Advances in computing power mean that numerical modelling will replace practical experimentation.

Answer: Wrong

In the mid 1960s Gordon Moore made the observation that the power of computer, which can actually be measured by the number of transistors contained in a microprocessor, would double every 18 months (figure 6). For the past 20 years this observation has come to be true, and as a consequence mankind has been wondering when computing power would be sufficient to equal the human brain or to simulate the real world. Also, will the computer power will a day be enough to replace experiments? This is what is going to be discussed here.

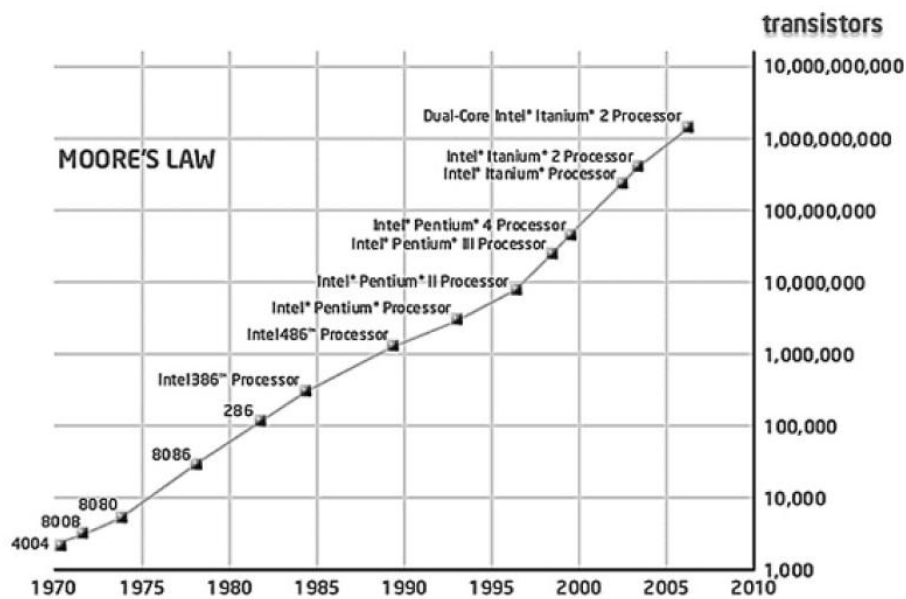


Figure 6: Moore's law for microprocessors.⁷

First of all, the accuracy of a numerical model, which is given by the spatial discretization, is going to be considered in this first part of the answer. As a definition, the smaller the spacing between the grid points of a numerical model is, the more accurate the simulation.

Based on a simple interpretation of the law, Moore's observation can be summed up in the following equation:

$$P = A \times 2^{\frac{1}{2} \times Y} \quad \text{where } A \text{ is the power of the computer at Year}(Y) = 0^8$$

Using the most powerful computer of 2008 for a direct simulation, it would not be possible to calculate more than a 10^8 grid point spatial discretization. Furthermore, the scale needed to fully describe the behaviour of a material with a complete 3D simulation is the lattice scale. Therefore, a quick calculation shows that for a direct simulation of physical phenomena at a lattice scale (10^{-9} m), the number of grid points needed for a 1 meter model would be:

$$(10 \times 10^9)^3 = 10^{27}$$

⁷ http://nano-taiwan.sinica.edu.tw/2008_WinterSchool/index.htm, viewed 13 Nov 2008.

⁸ Voller V. R., Porté-Agel F., (2002), Journal of computational physics 179, 698-703, Moore's Law and Numerical Modeling

This is obviously a very large number but if Moore's law is true, computer would be able to do it in 2100⁹. Considering this, statement is right. It is indeed true that advances in computing power mean that direct simulation of material behaviour at any scale would soon be possible and would replace experiments, even the most accurate ones.

However, the scale is not the only thing that matters in a numerical modelling. Indeed, models have to be built on proven laws and validated physical theories. The problem here is that scientists do not have formulas or equations to describe everything that is going on in the real world, even when considering just materials. As a consequence, if a mechanism is not very well known it cannot be used in a numerical model otherwise results would not be accurate at all, and no matter how small is the scale size.

That is also why real life experiments, and only them, can be used to build hypotheses and new theories or to verify them. It is absolutely not reasonable to do so with a numerical model because it works the other way: theory has to be established and verified first. As a consequence, considering this, no matter the power of the computer is, numerical modelling will never replace real experiments.

Furthermore, it sometimes happens that even if a model is supposed to be reliable, it gives completely wrong results compared to what happens in reality. For instance, an unknown mechanism for a particular condition during the experiment could indeed suddenly appear. This would never be taken into account in a numerical model and that is why even with the constant increase of the computing power models are only just closer to reality but never really match it.

As a conclusion, everything that has been said proves that the statement is wrong. Experiments will always be needed for science improvement, and to build new theories. Numerical models are only programmed by humans. As a consequence, their reliability is directly linked to our current understanding of the world and we are far from having discovered everything. Reliability has nothing to do with computing power and that is why numerical modelling will never replace practical experimentation.

The only hope is may be to find one day a universal formula which would unify science (physics, mechanics, chemistry etc...) by regrouping everything in a single equation. Scientists have been hoping for this for ages, but this is way beyond modern science and only pure speculation.

⁹ Voller V. R., Porté-Agel F.,(2002), Journal of computational physics 179, 698-703, Moore's Law and Numerical Modeling

Statement: The four terms hypoeutectoid, hypereutectoid, proeutectoid and microconstituent are unnecessary in describing plain carbon steel microstructures and are just part of the natural accumulation of technical terms that arise in any specialist subject.

Answer: Partially wrong:

The best way to answer this question is probably to define each of these technical terms, then take some representative microstructures of carbon steel and try make an accurate description of any of them to see if terms are necessary or not.

First of all, plain carbon steel is iron where the main alloying element is carbon with no particular requirements on any other component. Here is the typical phase diagram for carbon steel.

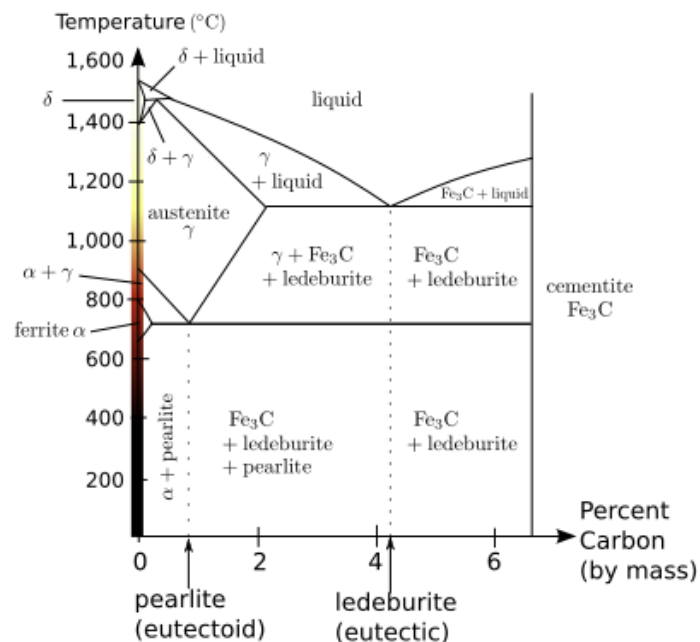


Figure 7: Carbon steel phase diagram.¹⁰

Important note: Everything that is going to be said here is by using that diagram at equilibrium.

Considering the three typical terms written in the statement, we can separate carbon steel alloys in typical categories:

- Below 0.77wt% C¹¹: hypoeutectoid
- Above 0.77 wt% C but below 2.14 wt% C here otherwise this is no longer a carbon steel but a cast iron: hypereutectoid
- Also, proeutectoid means formed at higher temperature than $T_{\text{eutectoid}}$;

¹⁰ http://en.wikipedia.org/wiki/Image:Steel_pd.svg, viewed 13 Nov 2008

¹¹ Ashby, M. F., Jones D. R., (2005), *Engineering Materials 2*, Butterworth Heinemann, p. 427

As a consequence, in order to get a bit familiar with these words, it can be said that at room temperature and at equilibrium, a hypoeutectoid steel will have some proeutectoid ferrite and a hypereutectoid carbon steel will have some proeutectoid cementite in its microstructure.

Here are some typical carbon-steel microstructures where these four terms are useful to describe them.

The microconstituents for the specimen figure 8¹² are:

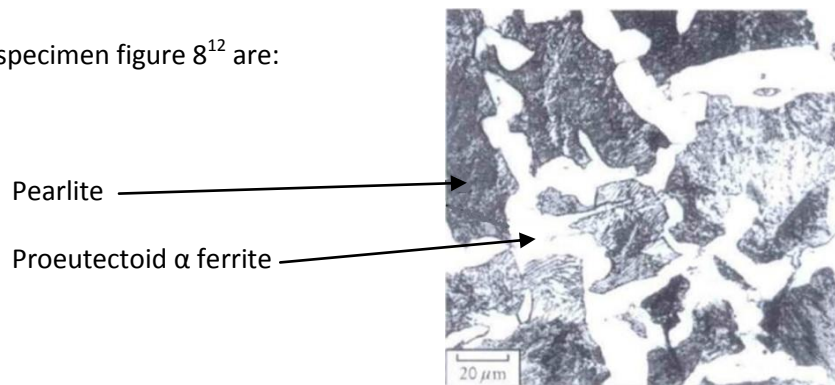


Figure 8: A hypoeutectoid steel carbon

The microconstituents for the specimen figure 9¹¹ are:



Figure 9: A hypereutectoid steel carbon

There is nothing more to say here. It is just obvious that only with 4 terms and 2 sentences, the specimen can be described.

As a conclusion the important thing is that these terms are only difficult at first look when their meaning is unknown. But when the mechanisms of the carbon steel transformation are well understood they are a great help in describing microstructures. Indeed, there are many possibilities of different microstructure for that kind of alloy that without them, we would get easily lost.

Plus, these terms are universal. This means that we can also use them for a zinc chromium microstructure for example or any other kind of alloy. So, yes it is true that we could describe a microstructure by avoiding these words (using wt% for instance) but it would not be convenient at all.

¹² <http://www.iut-acy.univ-savoie.fr/intranet/mph/fichiers/Semestre2/instruments-de-caracterisation-des-microstructures.pdf>, viewed 14 Nov 2008