Non-Ferrous Fasteners

非铁材质紧固件

by Thomas Doppke

The fastener industry is centered on the use of steel fasteners. Existing in a multitude of sizes, shapes, threads that vary with the job requirements they all have one quality in common, they are made of steel. However there is a small corner of the technology where non-ferrous fasteners reside. Who and why they exist is the basis of this article. While any metal may be made into almost any shape, this article will focus mainly on the threaded fasteners. Pins, clips and studs may be available but will only be touched upon, if at all.

What are your material choices for non-steel fasteners? Aluminum comes first to mind. Copper, titanium, zirconium have been heard of as have zinc, and tin. Other metallics? Magnesium, nickel, silver and gold, platinum, and lead may have unique and niche applications. The remaining metallics in the periodic table are not viable. Cobalt, Tungsten, Manganese, Chromium, etc. are extremely too expensive and offer no advantages over other choices. There are a few exotic metals made into select applications for unique industries which we will mention in passing. Many of these are not easily formable and require costly and time consuming labor to manufacture. Finally we must include ceramics, plastics, wood, and 21st century materials such as carbon fiber and composites in our non-steel list.

First, let's look at the properties of a steel fastener and what makes it so good at its job. Steel fasteners are strong, malleable, durable, cheap to manufacture, have a long history of usage and technology, are readily available worldwide, and come in variety of shapes and sizes to fit about every conceivable requirement. Why use anything else? For starters, the steel corrodes in the presence of moisture and many chemical environments. It does not get along well with other materials, setting up an electrical flow, called galvanic corrosion, which rapidly shortens the attachment's life. Its strength is gained at the cost of increased weight, a very important point in today's weight conscious world. However, it is not very conductive in electrical circuits. It is magnetic, an undesirable property in the presence of electrical components. And finally, certain cosmetic issues rule out steel parts in many applications. How are these issues addressed with non-steel fasteners?

A review of the areas where non-ferrous parts are found lists aircraft/aerospace, marine, motorcycle, medical, military, and limited transportation, and certain cosmetic areas. Electrical applications also have a need for conductive non-ferrous parts. The requirements that require deviations from the properties of standard steel parts and what the non-ferrous ones offer is as follows. Mainly non-ferrous parts are used in areas where corrosion, in whatever form, is a problem. Secondly, weight reduction without loss of strength is another requirement. Retention of strength under conditions of very high heat and extreme conditions require something more than a steel part.

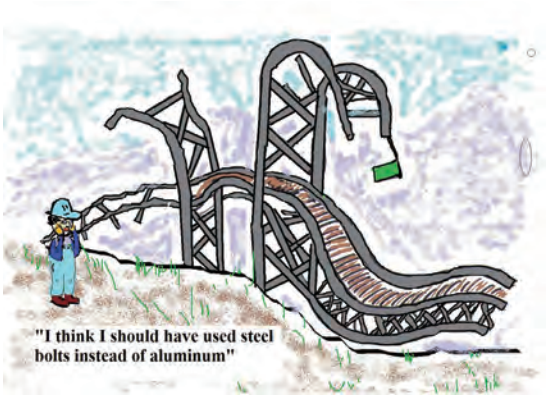
紧固件产业以使用钢铁紧固件为主。钢铁紧固件种类繁多，随功能需求在尺寸、形状及螺纹各异，共同特质是全由钢铁制成。不过在某些技术领域，非铁紧固件也具一定地位。本文探讨非铁紧固件的本质及其存在理由。虽然任何金属都可制成任何形状，本文重点在螺纹紧固件。若有必要，本文将顺带提起插销别针和夹扣饰钉。

使用非铁紧固件时你会选哪种材料？铝是最先想到的。铜、钛、锆、锌和锡也曾听说。其它金属呢？镁、镍、银、金、铂、铅，这些可能是专属特用材料。除此之外周期表其它金属都不适用。钴，钨，锰，铬等非常昂贵，比起其它选择并不具优势。有些异类特殊金属专门为特定产业制造，文中也会提到。这些金属许多成型不易，制造费时费工。最后，非铁材料还必须包括陶瓷，塑料，木材，以及21 世纪材料，如碳纤维及复合材料。

首先，让我们来了解钢制紧固件的特性，看看钢制紧固件如何在应用领域发挥功能。钢铁紧固件强度高，可冲压成型，经久耐用，制造成本低廉，使用和技术的历史悠久，全世界各地容易取得，还具有各种形状和大小，几乎所有想得到的需求都可符合。为什么还需使用其它材质的紧固件呢？首要知道，钢铁在水分和多种化学环境下必然锈蚀。钢铁难与其它材料共存，发生所谓电偶锈蚀，两者间产生电流，迅速缩短接合件使用寿命。钢铁具有强度，但是牺牲的却是重量增加，这对追求减重质轻的今日非常重要。然而，钢铁的电路导电性不佳。钢铁具磁吸性，这在电气部件存在的情况下非属必要。最后，表面涂装问题会排除许多钢制部件应用的可能性。在这些问题上，非铁材质紧固件的情况又如何？

回顾非铁部件应用，如下所示，包括飞机／航太、船舶、摩托车、医疗、军事、少数几种交通工具，以及某些表面涂装领域。电气方面的应用也需要可导电的非铁部件。以下概略叙述有别于标准钢制部件特性以及非铁部件所需的性能。多数非铁部件应用在任何锈蚀的地方。其次，重量减少但强度不减是另一要求。在高温和极端条件下还能保持强度，需要的就不只是钢制部件。最后，对于表面涂装的重视促成对非铁部件的需求，因其可依周边色彩搭配所需颜色。

就用量而言，铝制部件在非铁件清单中为最大宗。减重质轻导向使得许多产业选用金属板基材时，使用铝材而非钢铁材。铝材质轻，机械成型加工容易，所需能源低，取材容易，在许多情况比钢板便宜。进口钢铁取代许多在地供应来源，而且由于运作成本增加、卫生环境和安全问题以及原料成本上涨，炼钢厂先后关闭。铝材的问题



"I think I should have used steel bolts instead of aluminum"
"早知道就用钢制而非铝制螺栓了"

Finally, cosmetic concerns push the need for non-ferrous parts which can often be color coded to match surrounding areas.

By sheer volume aluminum parts lead the list. The drive to save weight has led many industries to use aluminum instead of steel as their basic material for sheet metal. It is light, easily formed with lower energy using machines, readily available and cheaper than sheet steel in many cases. Imported steel has replaced many local sources as steel mills shut down due to rising costs to operateion, health, environmental, and safety issues as well as the cost of raw materials. The problem is how to fasten the aluminum. One of the negatives of using a steel part is corrosion. Since almost all usages of aluminum sheet will be exposed to the weather in some manner or other, iron fasteners will rust. Various corrosion resistant finishes will delay it but rust will happen. In addition to the cosmetically objectionable corrosion, the part may lose strength and institute various other forms of failure over the service life. The repair of rusted parts is always a major concern and costly. Improper torqueing will lead to loosening of the steel fasteners which will relax easily as the fastener embeds itself into the soft aluminum substrate.

Aluminum parts do not 'bleed' corrosion in most instances so their use in visible areas, such as trailer bodies (both commercial truck and personal recreational) is an ideal application. Where there is insufficient clamping capacity to firmly attach the sheet metal, as in aircraft or large truck trailers, aluminum rivets are utilized in addition to bolts and the total number of parts is increased. Aluminum fasteners cost less than brass and stainless steel parts but more than steel ones. Since they require no maintenance their initial cost may offset the cheaper steel ones in some applications. Aluminum parts have the best strength–to-weight ratio of any commonly in use metal. Some compositions can be treated to be stronger than mild steel parts. Aluminum fasteners weight about one third as much as mild steel parts. Fastening aluminum with aluminum fasteners is the most practical method of attachment. Aluminum is non-magnetic but possesses a high rate on conductivity making its use in some electrical applications economical.

The downside of aluminum fasteners is the fact that they are indeed much lower in strength than steel parts. Their use should be limited to fairly low load bearing applications. They tend to corrode quickly in certain conditions while offering good resistance to ordinary atmospheric conditions. Chloride salts that are used for road de-icing and dust reduction in many countries are especially harmful to aluminum.

Before continuing, the corrosion factor should be discussed. In addition to general type of corrosion (rusting and weathering, and chloride attack) the issue of galvanic

在于紧固方式。钢铁材的缺点之一是锈蚀。几乎所有铝板材都会被暴露于会让钢铁锈蚀的天候。各种防蚀表面涂装虽然可延后锈蚀，但锈蚀终究会发生。除了会产生不佳外观的锈蚀外，部件强度也可能减损，在使用期间产生其它故障。维修锈蚀部件通常是主要关注的问题，成本也高。不当扭矩会使钢制紧固件嵌入质软铝基材时易于松弛，导致紧固件松动。

多数铝材部件锈蚀情况并没有“如血液一样淌流”的现象，所以铝材可使用在使用者看得见的地方，如拖车车体（商用货车和自用休旅车）即是理想的应用。夹紧力不足以紧固金属板的应用，例如飞机或大型卡车拖车，铝合金铆钉的使用可以补充螺栓的不足，零件总数因此增加。铝材紧固件成本比黄铜和不锈钢件便宜但比钢来得高。因铝制紧固件不需维修，其初始成本可抵销相当某些便宜应用的钢材。所有常用金属中，铝材部件有最佳的强度重量比。有些成分可加工处理使其强度高于低碳钢部件。铝制紧固件大约只有低碳钢部件三分之一重。铝材以铝制紧固件紧固是最实际的接合方式。铝材不具磁吸性，但具有高导电率，因此在某些电气应用上相当经济。

铝制紧固件的缺点是，它们的强度确实比钢制部件低许多。使用上必须局限在相当低负载的应用。在特定情况下它们往往迅速锈蚀，但对于普通大气状况却又具有良好的抗性。许多国家用在道路除冰和减尘的氯盐对于铝材尤其伤害。

继续往下说之前，应该先谈论锈蚀的因素。除了一般锈蚀（生锈、风化及氯化物侵蚀），应该要了解有关电偶锈蚀的问题。电偶锈蚀是因两种金属相互接触而发生。所需条件包括一个导电介质，大多数情况的充分条件就是空气中的水气，并且这两种金属一定要不同并相互接触。阳极金属和阴极金属相互作用就产生电细胞。以元素电偶锈蚀参照表来看，这两种金属若相隔越远，产生的电偶锈蚀就更快且更严重。电子从阳极元素流动到阴极元素。这两个元素相距越远，锈蚀速率越快。相较于一般锈蚀，电偶锈蚀严重许多，所以应该不惜代价倾全力去避免。另一个经常被忽视的因素就是，这两个元素分别的面积对于锈蚀速率影响重大。若是阳极面积较小而阴极面积较大的情况，则其锈蚀速率会比阴极面积较小而阳极面积较大的情况快得多。但是，锈蚀还是会发生。此图显示铝材结构某一部位以钢制铆钉固定。阳极大，阴极小，应该可以吧？绝对不可，这几支铆钉面积加总已是个大面积，再“加上”结构暴露在道路除冰情况盐份飞溅的面积。工程师决定改用不锈钢铆钉。结果却是错误的选择，这两

Galvanic Corrosion Table / 元素电偶锈蚀表

Most Anodic/最大阳极	Magnesium/镁
	Zinc/锌
	Beryllium/铍
	Aluminum/铝 1100 Series/系列
	Cadmium镉
	Aluminum/铝 2024-T4
	Mild Steel/Cast Iron
	Cr-Ni Stainless/铬镍不锈钢(300 Series/系列) Activated/活化
	Hastelloy/哈氏合金 “C”
Current Flow From Anode To Cathode/ 电流从阳极到阴极	Lead, Tin/铅，锡
	Nickel/镍(Activated/活化) Inconel/铬镍铁合金
	Hastelloy/哈氏合金 “B”
	Brass, Copper, Bronze/黄铜，紫铜，青铜
	Monel/蒙乃尔合金
	Nickel Alloys/镍合金(Passivated/钝化)
	Silver/银
	Titanium/钛
	Graphite/石墨
	Gold/金
Most Cathodic/最大阴极	Platinum/铂

corrosion should be mentioned. Galvanic corrosion occurs when two dissimilar metals are in contact with each other. The conditions required are a conductive medium, moisture in the air is sufficient in most cases, and that the two metals are dissimilar and in contact with each other. An electrical cell is set up with the cathode metal interacting with the anode metal. The farther apart the two metals are on the galvanic table the faster and greater the galvanic corrosion occurs. Electrons flow from the anodic element to the cathodic one. The farther apart the two elements are the faster will be the corrosion rate. Galvanic corrosion is much more severe than ordinary corrosion and should be avoided at all costs. Another factor often overlooked is that the respective area of the two elements plays a great part in the corrosion rate. A small anode against a large area of cathode will corrode much faster than a small cathode against a large area of anode. However, corrosion will still occur. The illustration shows are an area of aluminum structure held together with steel rivets. Large anode, small cathode- should be OK? No, the areas of the several rivets add up to a large volume PLUS the

种元素在电偶锈蚀表上相距更远，提供更快的锈蚀速度！

这个电偶锈蚀参照表显示一些元素依电动顺序排列。参照表列出几乎所有曾经制造的金属，但未必有用，因为没有人会使用所有的元素。我编辑了这个参照表，包括许多本文中我们正在讨论的金属。有时电偶锈蚀可能发生在同一类金属（一种铜与另一种铜等等），一般来说只是轻微影响。再次指出，以元素电偶锈蚀参照表，两元素相隔越远，锈蚀更快更严重。

铝制与钢制紧固件可取得的配置、尺寸、头型和类别一致。铝制螺丝和螺栓的装配存在若干限制。铝材与铝材接合，相较于钢材接合，发生螺纹交错的倾向较大。铝制紧固件与铝基材接合，装配必须有某种润滑，安装速度应减慢，（这两项操作不当造成 80% 以上的铝材与铝材装配问题，例如擦伤和螺纹交错）。单单是铝制紧固件可能要以一整篇文章来讨论（或许真的得这么做）。非铁紧固件使用量居次的是由钛金属制成的紧固件。钛金属紧固件主要使用在海洋、医疗、航太、军事、化工等产业。大部分钛金属部件应用在以减轻零件重量来抵销高成本的体育用品上，如轻质自行车和摩托车。钛金属部件为人所知的是强度高，重量轻以及耐锈蚀，具有紧固件金属材料中最高的强度重量比。因为对氯和氯化合物完备的抗蚀性，钛金属紧固件应用在化学锈蚀性的环境，例如纸浆和纸张制造业。这种对于氯的抗性使得钛金属成为石油和天然气产业，海水淡化和海事产业最佳的选择。

就工商业而论，纯钛金属（2级钛）是最常用的材料，含少量铝和钒成分的钛合金（5级钛）使特定紧固件有更好的成型性。含微量钯成分的钛合金（7级钛）为化工业超高锈蚀应用提供了抗蚀性最高的合金。

钛金属紧固件其它的特性是电导率和热导率相对较低，熔点高达（<1650℃/ 3000℉），并且不具磁吸性。加工处理必须特别谨慎，因为加工刀具不够锋利或冷却方法不正确，钛金属容易软化擦伤。与铝金属相似，钛金属在空气中氧化迅速，在表面形成不易被侵入不透性的氧化物涂层。可能受浓缩强酸侵蚀，但几乎对于所有稀释的酸仍具抗蚀性。与卤素和氧产生反应的温度较高（约550℃）。在氮气中燃烧的温度在约800℃，因此焊接必须在惰性气体复盖的状况中完成。军事用途包括飞机，舰艇的装甲和导弹。钛金属具有生物相容性（无毒，不受人体排斥），使钛螺丝成为理想的植入医疗用物。

铜金属使用的历史可追溯到文字记载之前。

area that this structure was exposed to was subjected to salt splash from road deicing. The engineers decided that they should use a stainless steel rivet instead. Bad choice-these two are even farther apart in the galvanic table and gave an even faster corrosion rate!!

The table shows some of the elements arranged in electromotive order. Tables with almost every metal have been made but are useless as no one really uses all the elements. I have edited the table to include many of the metals that we are discussing in this article. While some galvanic action can occur even within the same groupings (one kind of brass vs another and so on) generally the effect will be very minor. Again, the farther apart they are in the table, the faster and more severe the corrosion will be.

Aluminum fasteners are available in all steel configurations, sizes, head styles and types. Some restrictions on assembly with aluminum screws and bolts exist. The tendency for the threads to seize onto each other is greater with aluminum to aluminum joints than with steel. Some sort of lubrication is necessary for assembly and speed of installation should be lower when using aluminum fasteners into aluminum substrates (these two items account for over 80% of aluminum to aluminum assembly problems- galling and seizure). An entire article on aluminum fasteners alone could be written (and perhaps it will be).

The next largest volume of non-ferrous fasteners is those made of titanium. Their use is mainly in marine, medical, aerospace, military and chemical processing industries. A large number of titanium parts find application in sporting goods such as in light weight bicycles and motorcycles where the weight savings offset the high cost of the parts. Titanium parts are known for being strong, lightweight and corrosion resistant and have the highest strength-to-weight ratio of any of the other metals used for fasteners. Being fully resistant to the effects of chlorine and chlorine compounds, they are found in industries where such chemicals abound such as pulp and paper manufactures. This resistance to chlorine makes them an excellent choice for oil and gas, desalination, and marine industries.

Commercially pure titanium (grade 2) is the most commonly used material while small amounts of aluminum and vanadium (titanium grade 5) allows better formability for specific fasteners. A minute amount of palladium (titanium grade 7) forms the most corrosion resistant alloy for the ultra-corrosion applications of the chemical industries.

Some other properties of titanium fasteners are the facts that they have a fairly low electrical and thermal conductivity, a high melting point (<1650°C/ 3000°F), and are non-magnetic. Machining requires some caution as the metal will soften and gall if sharp tools and correct cooling methods are not employed. Like aluminum, titanium oxidizes rapidly in air, giving it an impervious surface oxide coating against intrusion. It is attacked by concentrated acids but resistant to almost all diluted ones. It reacts at higher temperatures (about 550°C) with halogens and oxygen. It will burn in a nitrogen atmosphere at about 800°C making welding a process that must be done under an inert gas cover. Military usages include aircraft, naval ships armor, and missiles. It is biocompatible (non-toxic and not rejected by the body) which makes titanium screws ideal for medical implants.

Copper has a history extending back before written records. While used today for its electrical conductivity properties, it has little usage for fasteners beyond small parts in electrical applications. Although some high current parts are of considerable size their usage

铜金属导电性的使用虽然今日常见，除了小尺寸部件应用在电气领域，铜金属的使用几乎是没有。用于高电流的部件有些尺寸相当大，但是其用途大抵和小螺丝一样。铜的导电率比铝更好，但是不如银或金，却是便宜许多。为了降低铜螺丝的成本，有一个方案是以包复的方式（类似许多国家钱币的铸造），外涂层的铜材包复在铝基材上，目前使用在小型电气的连接应用。

锆的化学和物理特性与钛相近。锆金属紧固件使用在锈蚀严重到无法使用不锈钢，镍合金和钛的环境。盐酸、硝酸和有机酸，甚至强碱如氢氧化钠对于锆金属螺栓影响有限。只有钽金属螺栓可以超越锆金属的抗蚀性。

锌和锡的紧固件尺寸也相当小，使用限于需求相容性的小型压铸件。这两种金属的使用量都不显着。大多数是小型插销别针以及其它低熔点物件内含小尺寸的锌／锡铸件组件。

作为一种紧固件材料，镍金属本身并不单独使用。添加其它金属，增进抗蚀和其它特性于是成为镍合金。但是，有几种合金其化学成分含镍相当多。最常见的镍合金是 Monel（蒙乃尔合金）。这种合金基本上含约67%的镍和大部分的铜，应用在海事产业和其它高锈蚀的领域。如本文提到的其它紧固件材料，镍合金使用领域也非常相似。差别在成本和可用性。蒙乃尔合金的成本比不锈钢高，但提供更好的锈蚀防护，尤其在高温状况。与所有其它镍合金相似，蒙乃尔合金加工困难。在大多数情况，减低加工和进料速度可防止工件硬化和擦伤。如果蒙乃尔合金与钢铁制部件接触，将发生电偶锈蚀；曾经有一艘船艇不到几个星期就发生龙骨解体，已知是这样的错误所致。

Inconel®铬镍铁合金是另一个以镍为主，耐高温，高抗蚀，广泛使用的合金系列。镍的成分从50%至72%不等，铜次之。这种合金在很宽的温度范围都可保住其强度，对于氧化以及上文所述的锈蚀元素都具抗性。Inconel 合金是Special Metals Corp. (特殊金属公司)的商品名。

Hastelloy® 哈氏合金是另一个以镍为主，特性大致相同的合金系列。有许多种成份类型（约22种），各有几种不同金属不同的成份含量。适用于高温和高应力。在加压的化学反应槽与核反应炉体的应用可取代钢制部件。Hastelloy是Haynes国际有限公司的注册商标名称。

由此可见，许多非铁紧固件的使用很相似。主要使用在高温和高锈蚀的环境。这些部件的高成本让使用限于例如军方、政府和大型企业的大资金投资。

is still much the same as the small screws. Its conductivity is better than aluminum and less than silver or gold but is much cheaper. In an effort to reduce the cost of copper screws a clad version (similar to coinage that many countries are using), consisting of a copper outer coating over an aluminum base, is in use for small electrical connections.

Zirconium's properties are chemically and physically similar to titanium. Fasteners are used in areas where the corrosive environment is too severe for stainless steels, nickel alloys and titanium. Hydrochloric, nitric and organic acids and even alkalines such as sodium hydroxide have little effect on zirconium bolts. Only tantalum bolts can surpass zirconium's corrosion resistance.

Zinc and tin fasteners tend to also be rather small in size and limited to usages in small die casting where compatibility is required. No appreciable volume of parts exists in either metal. Mostly small pins and other low melting point items that hold components of small zinc /tin castings.

Nickel has no known usage as a fastener metal by itself. Alloyed with other metals it adds corrosion and other qualities to the mixture. However, there are several alloys which contain a majority of nickel in their chemistry. The most commonly known one is Monel. Consisting of basically about 67% nickel and mostly copper, this alloy finds numerous usages in the marine sector and other high corrosion areas. Like the other fastener materials mentioned here, the usages are pretty much similar. The differential being the cost and availability. Monel costs more than stainless but offers better corrosion protection, especially at higher temperatures. Like all the nickel alloys it is very difficult to machine. Slow speed and low feed rates will prevent work hardening and galling in most instances. Galvanic action occurs if Monel is placed against steel parts and one boat keel is known to have disintegrated within weeks when such a mistake was made.

Inconel® is another nickel based, high temperature, and highly corrosion resistant series of alloys in use widely. Nickel content varies from 50 to 72% with copper the next largest addition. It retains its strength over a wide temperature range and resists oxidation and the usual elements of corrosion noted above. Inconel is a trade name of the Special Metals Corp.

Hastelloy® is another series of similar nickel based alloys with much the same properties. There are several (about 22) compositions available, all with varying amounts of several other metals. Good in high temperatures and high stress areas. It replaces steel parts in places like pressure vessels in chemical and nuclear reactors. Hastelloy is a registered trade name of Haynes International Inc.

It can be seen that there is a similarity of usage in many of the non-ferrous fasteners. High temperatures and corrosive environments predominate. The high cost of these parts limits them to big money investments such as military, governments, and large corporations.

The exotics. While the balance of metals is not commonly found in other than a few chemical compounds or museum curiosity pieces, a few exotics do show up on the fastener shelves. Here are a few that I found that are actually made into fasteners. Beryllium is often mentioned in conjunction with copper. Used as areas where the possibility of an explosion could occur (gas and combustible substances processing) it has a place. Beryllium, by itself, exists as a fastener only in some limited space vehicle applications where it's high strength-to-weight ratio and long fatigue life makes it a selection choice. It has low ductility

异类特殊金属。其余的金属虽然不常见，除了使用在少数几个化合物或者博物馆满足科学好奇心的东西，有一些异类特殊金属也会出现在紧固件的陈列架上。这里有少数几样料我发现实际制作成紧固件的材。铍金属(Beryllium)通常和铜相提并论。使用在有爆炸可能的地方（气体和燃烧物质处理场所）。铍金属本身即是紧固件材料，仅限于太空载具的应用，取其强度重量比较高以及疲劳寿命较长的特性。铍金属延展性低，对于凹陷反应敏感，因此必须小心处理。其高成本只有政府机构承担得起。其形式通常是实芯或空芯铆钉。

钼金属（Molybdenum）通常是钢制部件的合金元素。钼金属紧固件可以公制和英制尺寸，向专业紧固件制造商订制。它的熔点极高（2620℃），在高温下还可保有其强度。它使用于军方和航太载具的接合。因为在约600℃有氧气的存在下会迅速氧化，在高温应用的条件限于没有氧气存在的空间下（高温真空炉、玻璃生产，当然还包括外太空）。

钽金属 (Tantalum)螺栓已为人知的特性是优异的抗锈蚀性和化学惰性。其使用是无法以镍、钛或锆合金部件满足抗蚀需求的情况。钽金属在高温2000℃ 仍具有高强度（熔点约3000℃）。具有金属所有典型的性能，其抗蚀性则被描述为与玻璃相近。它是最具生物相容性的金属之一，由于高密度（16.6克/立方厘米）因而具有射线不透性，在150℃ 对于几乎每一种介质都具化学抗性。

贵重金属，金，银和铂使用也出现在紧固件的舞台，但限于珠宝类的外观美化和装饰。以其质软、不适合任何紧固用途，略过不谈。

非铁材紧固件若是没有谈到塑料，陶瓷和木材这些非金属材，那就不算完善。

陶瓷螺栓通常由两者之一的材料制成； 氧化铝或是氧化锆。氧化铝和氧化锆是可取得材料之中最耐高温的材料，耐热温度达 2730℉（1500℃）。除了优越的耐蚀性和化学抗性，由于不具磁吸性因而使用在各种高电压应用领域。氧化铝(Alumina)通常是首选材料，而氧化锆(Zirconia)的选用是有额外的强度和钢度需求。两者可以公制和英制尺寸由供应商提供。

非铁材紧固件若是没有谈到塑料，更是不算完善。高分子聚合物螺栓当中，强度最高和钢度最大的一种是由聚酰胺-酰亚胺塑料所制成。Torlon® 螺栓（Solvay 塑料公司注册商品名）使用塑料聚酰胺酰亚胺塑料制成，在极端条件，从低温温度到高温525℉（275℃），具有优异的强度

and is very notch sensitive and must be handled with care. Its high cost can only be borne by governmental agencies. Its usual form is that of a solid or blind rivet.

Molybdenum is usually found as an alloying element in steel parts. However metallic molybdenum fasteners are available in most metric and inch sizes from specialty fastener manufacturers. It has an extremely high melting point (2620°C) and can maintain its strength at high temperatures. Its usage is in military and space attachments. Since it oxidizes quickly in the presence of oxygen at around 600°C its high heat applications are limited to areas with an absence of oxygen (high heat vacuum furnaces, glass production, and, of course, outer space).

Tantalum bolts are known for their superior corrosion resistance and chemical inertness. It is used when nickel, titanium or zirconium alloy parts are not enough to meet corrosion requirements. It has high strength up to 2000°C (melting point is around 3000°C). Having all the typical properties of a metal, its corrosion resistance is said to be similar to glass. It is one of the most bio-compatible metals, is radio-opaque due to its high density (16.6 g/cc) and is chemically resistant to almost every media at 150°C.

The noble metals, gold, silver and platinum, have usage in the fastener arena but as cosmetic and decorative jewelry items. Too soft for any other purpose, we'll skip over these.

No discussion of non-ferrous fasteners is complete without a mention of the nonmetallic contributors; plastics, ceramics, and wood.

Ceramic bolts are generally made of one of two materials; alumina or zirconia. They are the most thermally resistant materials available, good to 2730°F (1500°C). In addition to their outstanding corrosion and chemical resistance, their non-magnetic properties find them used in areas of various high voltage applications. Alumina is the first material usually chosen while zirconia is called for when additional strength and toughness is needed. They are available from suppliers in most metric and inch sizes.

No discussion about nonferrous fasteners is complete without mentioning plastics. One of the strongest and toughest polymer bolts available is made from polyamide-Imide plastic. Trade named Torlon®(registered to Solvay Plastics), bolts made of polyamide-Imide show exceptional strength and stiffness from cryogenic temperatures up to 525F (275C).They have excellent wear resistance as well as inertness to strong acids and most organic compounds. They are not metallic so strength will never be much of a concern. Their usage is in appliances, medical devices and such. However, it is the most metal-like of the plastics.

Polyimide bolts made from Dupont's Vespel® are one of the most temperature resistant of the plastic materials used for bolts and fasteners. Good to 350°F (288°C) for continuous service and 900°F (480°C) for intermittent exposure. Resistant to common solvents, acids, and oils, its low coefficient of friction adds to its positives. Available also in metric and inch sizes, it is found in automotive, aerospace, industrial equipment and semi-conductor areas.

Kynar® (product of Boedeker Plastics) bolts are made of the plastic compound PVDF, a fluoropolymer compound of great stability when exposed to harsh thermal, chemical and ultraviolet condition. They are used mainly in pharmaceutical processing. Readily available in sizes to fit the market.

PEEK (polyetheretheketone) is the trade product of Victrex Manufacturing Ltd, and sold as Victrex®. Like the rest of the plastics

和刚度。这种高分子聚合物螺栓具有优异的耐磨性，并且对于强酸和大多数有机化合物都具有惰性。高分子聚合物螺栓不是金属，所以强度通常不在考虑范围。高分子聚合物螺栓使用在家电，医疗设备这类领域。但是，这种高分子聚合物是最具有金属特性的塑料。

聚酰亚胺(Polyimide)螺栓使用杜邦公司的Vespel® 塑料制成，是使用于螺栓和紧固件最耐高温的塑料之一。耐热特性是持续使用350°F（288°C），以及间歇暴露900°F（480°C）。能抗常见的溶剂、酸和油。以其摩擦系数低，这又是另一优点。以公制和英制尺寸可在市场取得，应用于汽车、航太、工业仪器设备和半导体领域。

Kynar®（Boedeker塑料公司产品）螺栓使用塑料聚偏氟乙烯PVDF复合物制成，PVDF复合物是一种含氟聚合物的化合物，暴露在极端高温，化学和紫外线条件下仍有极佳的稳定性。主要使用于制药加工。目前有各种尺寸大小供应市场需求。

聚醚醚酮（polyetheretheketone，简称PEEK）是Victrex 公司的商标产品，以Victrex®销售。如同其它塑料部件，PEEK 摩擦系数低，对于各种化学物质、溶剂、酸盐类、油和蒸汽都具有化学抗性。在温度高达350°F（175°C）还有良好的强度。

PTFE可由几个供应商取得。最初由杜邦公司以Teflon®(铁弗龙)商标品名销售。目前专利保护期已过，有几家供应商随后争夺市场。PTFE 对于大多数化学品具有良好的抗性，可使用温度达500°F（260°C），健康纯度优良无健康危害，可使用于医疗相关领域。相较于大多数其它塑料，PTFE的强度较低，尤其在较高温度情况。

尼龙紧固件常见使用在许多非关键的零组件，也是平常五金商店所卖的普通材料。尼龙是现在广泛通用的塑料名称，但最初是杜邦公司所取得的专利。尼龙的强度在市售塑料中最高，在某些应用中与低碳钢相近。在每个塑料应用的领域，例如玩具、家电、汽车零组件，以及许多其它日常用品中，几乎都可看到尼龙的使用。

塑料紧固件是非铁制紧固件的一部分。塑料紧固件有一些共同特质。塑料紧固件比金属部件脆弱许多、遇热可能会损坏，这样的临界点对于金属来说，根本不须担心。在负载下塑料紧固件往往会慢慢蠕动爬行（冷流），直到松弛为止（有些塑料比其它的放松的程度少许多，但是时间还是作用在于塑料紧固件的紧密度）。塑料紧固件应用在医疗、化工产业的居多。但有些塑料种类

parts, it has a low coefficient of friction, and is chemically resistant to a wide variety of chemicals, solvents, acids salts, oil and steam. It has good strength in temperatures up to 350°F (175°C).

PTFE is available from several suppliers. Originally marketed as Teflon® by Dupont . Patents have expired and several sources contend for the market. It has great resistant to most chemicals, is usable up to 500°F (260°C), and is of excellent purity for health and medical applications. It is fairly weaker than most other plastics, especially at higher temperatures.

Nylon fasteners are seen in many non-critical components and are the usual material of parts sold in hardware stores. Nylon is now more of a general plastic name but was originally patented by Dupont. It has the greatest strength of any commercially available plastic, approaching mild steel in some applications. It can be found in almost every plastic application, toy, appliance, automotive components, and numerous other everyday items.

Plastic fasteners are a part of the non-ferrous grouping . They all share some traits. They are very much weaker than metal parts. They can be thermally destroyed at heat levels metals don't even worry about. Under load they tend to creep (cold flow) until they loosen (some much less than others but still time acts upon their tightness). They are found in the medical and chemical industries mostly. Some types have use in other industries as noted. Plastics can, and are, modified by the addition of many other ingredients. Like making soup, various things are added to change the outcome of the stew.

Glass fiber, beads, various resins to harden, to soften, to make ultraviolet resistant, anti-fugal chemicals, lubrications, and so on, an endless list of add ins. When using a plastic fastener, get the full list of what is in it and how those add ins affect the properties. Plastic properties are very temperature dependent. Values listed should be used with attention to the temperature at which the tests were run. Some plastics retain more strength at higher heat than others.

Finally, Modern science is developing new materials daily. Carbon fiber, new plastics appear with each application. New fasteners for new usages are being tried out currently.

Wood is the oldest material used by humankind. We stop here, letting you think upon the history of threaded wooden studs and such.

Following is a chart of sorts that lists some properties of nonferrous fasteners with whatever data that could be found about them. The data on plastics is a wild stab at what is an approximation of middle of the road compounds. This is only for comparison as one value could be twice what another formulation yields. The plastic values especially vary tremendously with heat. Values given here are for approximate compounds at about 150°C.

When using non-ferrous fasteners the possibility of a galvanic coupling exists and should ever be in one's mind. One case that shows this was an engineer's idea to use a plastic attachment onto n aluminum sheet. The part was colored black for appearance's sake. When corrosion occurred he was dumbfounded. He later was informed that black colorant in plastics is carbon black. See the table for where aluminum and carbon are!

Non-Ferrous Metal Properties

(Data below from best available sources):

则应在其它如上所述的产业。塑料借由添加多种其它成分可以达到改质的目的，目前实作也是如此。好比烹煮汤品，为了改变煮出来的结果，可添加入各种不同的东西。

玻璃纤维、玻璃珠，还有各种树脂的添加可使塑料硬化、软化、防止紫外线，成为抗菌防霉的化学品，或润滑等等，例子多到无法胜数。使用任何一种塑料紧固件，务必取得成分完整资料，并了解这些增添物质如何影响该塑料的特性。塑料的特性对于温度的依赖性非常高。使用下列表中所示数值，必须注意测试温度。有些塑料比别的塑料在高温下反而具有更高的强度。

最后必须说，现代科学每天都在发展新材料。有新的应用，就有新型碳纤维塑料的出现。每个时刻都有新型紧固件在新的应用进行测试。

木材是人类所使用最古老的材料。我们在此结束本文探讨，由你来想想木制螺纹螺钉的历史，以及其它紧固件材料相关的事。

下表列出非铁材质紧固件的一些特性，连同一些找到的相关资料。下列数值是依据塑料化合物特性约略定出的中间近似值。表中数值仅作为比较，因为任何一个数值在另一个配方可能得出两倍的数值。塑料的数值尤其容易受温度影响，变化很大。表中所示数值为该化合物近似值，温度约在150℃。

使用非铁材质紧固件，必须在心中永远谨记，电偶锈蚀发生是有可能的。有个案例显示这一点的重要性。有个工程师曾经出这样的主意：使用一个塑料接合部件来紧固N片铝板材。这个部件的外观呈黑色。锈蚀发生，却让这个工程师想不透。后来别人告诉他，他才明白，原来那个塑料的黑色着色剂竟然是炭黑。在电偶锈蚀表中，请看看铝和碳究竟在哪里！

非铁金属特性

（以下数值来自目前所能取得最佳来源）

	Tensile Strength Ksi (MPa) 拉伸强度 Ksi（兆帕）	Yield Strength Ksi (MPa) 屈服强度 Ksi（兆帕）	Elongation 拉长（%）	Reduction Area 减少面积（%）	Melting Point 熔点℃（℉）
Aluminum/铝			In 2 Inches/英吋		1220(660)
2024-T4	62(428)	40(276)	10	-	
6061-T6	42(290)	35(242)	10	-	
6262-T9	51(352)	47(324)	5	-	
7075-T73	68(470)	56(383)	12	-	
Titanium/钛	70(485)	50(345)	28	57	3040 (1670)
@100C	56(383)	37(256)	31		
@300C	33(229)	18(127)	43		
@450C	26(178)	11(74)	34		
Zirconium/锆	55(379)	40(276)	12 (in 1 inch/英吋)		3365(1852)
+ 2-3% Niobium/铌	70(483)	50(345)	12 (in 1 inch/英吋)		3344 (1840)
Nickel Base* 以镍为主材					
Monel 1 蒙乃尔合金	87 (600)	60 (415)	20		-
Monel 2 蒙乃尔合金	80 (552)	40 (276)	30		-
Iconel® 铬镍铁合金	128(880)	67 (460)	50		2350-2460F 1290-1350C
Hastelloy® 哈氏合金					
@400C	90(621)	35(241)	70		
Molybdenum/钼					4748(2620)
Tantalum/钽	40(276)	25(172)	50		5642(2996)
+2.5%W	55(379)	35(241)	30		
+10%W	90(620)	70(482)	30		
Ceramics/陶瓷					
Alumina/氧化铝					3762 (2072)
Zirconia/氧化锆					4919 (2715)
Plastics/塑料**					
Polyamide-Imide 聚酰胺 - 酰亚胺	17(117)				
Polyimide 聚酰亚胺	5-10 (40-70)				
PVDF 聚偏氟乙烯	7 (50)				
PEEK 聚醚醚酮	14-51(100-350)				
PTFE 聚四氟乙烯	2 (13.5)				

*Nickel based alloys are available in as many as 25 different compositions per each 'name'. The data listed is typical of some of the compositions. Actual data for a specific composition may vary widely.

** Plastic properties can vary extremely from one compound to another. The exact plastic formulation needs to be known to approximate any data beyond what is guessed at here.

*镍合金在每个不同的“名称”下，有25种化合物可取得。表中所列为某一些化合物的典型数值。特定化合物的实际数值可能变化很大。

**塑料属性可能随各种化合物而异。必须得知确实的塑料配方，以便在本列表约略估计的任何数值之外得出近似值。