

Refractory Metal Fasteners for Extreme Conditions: The Basics

by Martyn Lewis, Group Business Development Manager,
Goodfellow Cambridge Limited, martyn.lewis@goodfellow.com

There is a wide range of metal fasteners commonly available for standard applications, but what if your application is at very high temperature or in a highly corrosive environment? Sometimes the more commonly available fasteners are just not up to the job. Enter high-performance refractory metal fasteners. Refractory metal fasteners – nuts, bolts (also called screws or machine screws) and washers – are ideal for situations that involve high temperature, high voltage, magnetism and harsh corrosive environments.



Refractory metals are commonly considered to include **tungsten, tantalum, niobium, molybdenum and rhenium**. All except rhenium can be used in the fabrication of refractory metal fasteners. Rhenium is not used, among other considerations, because of its price; as one of the most expensive metals, a standard M5x50 bolt would contain around \$100 of material before even considering manufacturing costs.

A wider definition of refractory metals includes titanium, vanadium, chromium, zirconium, ruthenium, rhodium, hafnium, osmium and iridium. Of these metals, the one found in everyday use as a fastener material in applications as commonplace as motorcycles and mountain bikes is titanium, where it is used for its light weight, strength and corrosion resistance.

Properties of refractory metals

The identifying characteristic of refractory metals is their resistance to heat, notably a melting point above 2000°C (over 2400°C for the four materials discussed here), compared to those of stainless steels, which range from approximately 1400°C to 1500°C. Other characteristics include high hardness at room temperature, relatively high density, chemical inertness, and stability against creep deformation at very high temperatures. “Creep” refers to the tendency of metals to slowly deform under stress, making resistance to creep of utmost importance for fasteners used in extreme conditions.

TABLE 1:
Properties of refractory metals (99.9% pure)

	Niobium ^[1]	Molybdenum ^[2]	Tantalum ^[3]	Tungsten ^[4]
Melting point (°C)	2468	2617	2996	3410
Boiling point (°C)	4742	4612	5425	5660
Density @ 20°C (g cm ⁻³)	8.57	10.22	16.6	19.3
Tensile modulus (GPa)	104.9	324.8	185.7	411
Hardness – Vickers	115-160	200-250	90-200	360-500

TABLE 2:
Comparison of material strengths for commonly found fastener materials with those of refractory metals

	ULTIMATE STRENGTH (also known as Ultimate Tensile Strength, or Tensile Strength) MPa	YIELD STRENGTH MPa
300 series Stainless Steel (annealed-strain hardened)	517-861 ^[5]	206-690 ^[5]
400 series Stainless Steel (martensitic, hardened and tempered)	861-1241 ^[5]	655-930 ^[5]
Steel fasteners grade 8.8	800 ^[6]	640 ^[6]
Steel fasteners grade 10.9	1040 ^[6]	900 ^[6]
Steel fasteners grade 12.9	1220 ^[6]	1080 ^[6]
Molybdenum (hard)	620-690 ^[2]	550 ^[2]
Molybdenum (annealed)	485-550 ^[2]	415-450 ^[2]
Niobium (hard)	585 ^[1]	550 ^[1]
Niobium (annealed)	330 ^[1]	240 ^[1]
Tantalum (hard)	760 ^[3]	705 ^[3]
Tantalum (annealed)	172-207 ^[7]	310-380 ^[3]
Tungsten	689 ^[8] -4000 ^[9]	517 ^[8] -1570 ^[10]

Disclaimer: All values given in this article are intrinsic values for the materials themselves, rather than fasteners, unless otherwise indicated. Actual fastener performance values will depend on manufacturing process, purity/composition and usage environment. The values given should be taken as a guide only, and do not imply a guarantee of a minimum or maximum performance of any fasteners offered by Goodfellow or any other company. The customer should test any fasteners themselves before incorporating them in any project.

Dimensional standards for fasteners

There are various standards that should be used when specifying fasteners. Listed in Table 3 are the most common ones for metric sizes. For inch-threaded fasteners, different standards are applicable. There are a number of different standards, even within each system, that can be applicable, depending on the size of the fastener, and care should be taken to specify the correct standard.

Amongst other things, these standards give measurements and tolerances for the bolt head, details of the thread pitch and surface roughness. These standards also give details of mechanical properties for fasteners made from steel, but fasteners made from refractory metals are a specialist niche and their mechanical properties are not covered by current standards.

Standards define the dimensions of fasteners so that components from different manufacturers can be used interchangeably.

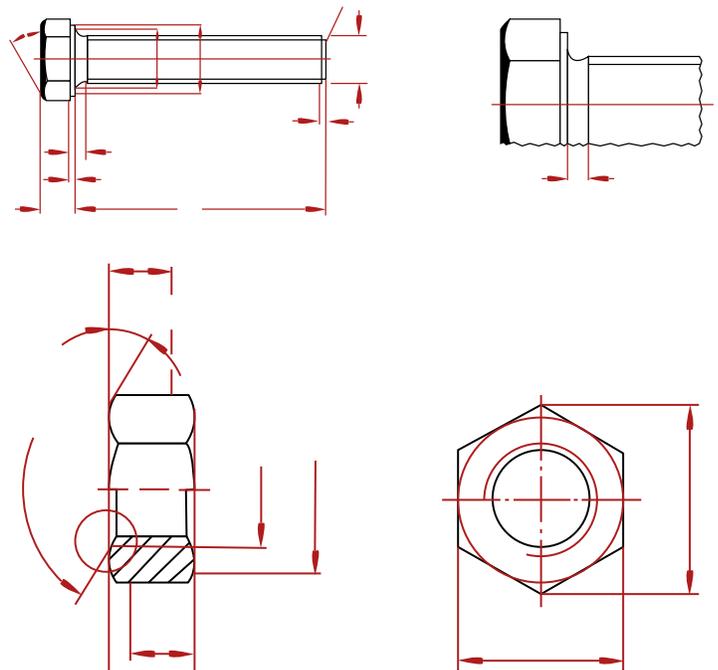


TABLE 3:
Dimensional standards for fasteners

	DIN / ISO		ANSI
	Current standard*	Expired standard, but still commonly quoted	
Nut	ISO 4032:2012 Hexagon regular nuts (style 1) - Product grades A and B		ASME B18.16M:2009 (Prevailing-torque type steel metric hex nuts and hex flange nuts)
	ISO 8673:2012 Hexagon regular nuts (style 1) with metric fine pitch thread - Product grades A and B	DIN 934	
Bolt	ISO 4017:2011 Hexagon head screws - Product grades A and B	DIN 933	ASME B18.2.3.5M:2011 (Metric hex bolts)
			ASME B18.2.6M:2012 (Metric heavy hex bolts) - for sizes M12 to M36
			ASME B18.6.7M:2000 (Metric machine screws)
Washer	ISO 7089:2000 Plain washers - Normal Series - Grade A	DIN 125	ASME B18.22M:2010 (Metric plain washers)

** The current ISO standards have expanded the range of sizes that were covered by the DIN standards, but for smaller sizes the older standard can be considered as equivalent or interchangeable in many cases. However, care should be taken that the fastener is being specified to the correct standard, and that the parts are interchangeable if this is a requirement.*

Snapshot of Refractory Metals

Tungsten has the highest melting point of all metals (3410°C) and is often the base of a range of tungsten-copper-nickel alloys used for radiation shielding; these alloys provide a 50 percent increase in density compared to lead. Fasteners made from tungsten and its alloys can, therefore, be used in radiation shielding applications and are also used in military applications (e.g., armour).

Niobium finds application in atomic reactors because of its corrosion resistance. Fasteners made from niobium or from nickel-, cobalt-, and iron-based superalloys containing niobium are found in jet engine parts, gas turbines, rocket subassemblies, advanced airframe systems, and heat-resisting and combustion equipment.

Tantalum has a corrosion resistance similar to glass but the mechanical properties of a metal, making it an excellent choice for extremely corrosive environments. Fasteners made from tantalum can be found in the chemical processing, mining, energy, pharmaceutical and metal processing industries. Tantalum is also radio-opaque, making tantalum fasteners useful in x-ray applications.

Molybdenum maintains its strength at high temperatures, making molybdenum fasteners ideal for applications where both high temperature and strength are needed. These fasteners are used in the semiconductor industry, the manufacture of armour and aircraft parts and in industrial motors.

Application areas for refractory metal fasteners

Depending on the metal or alloy being used, refractory metal fasteners can find application in:

- Furnaces
- Radiation shielding
- Armour
- Atomic reactors
- Jet engine parts
- Gas turbines
- Rocket subassemblies
- Airframe systems
- Heat-resisting and combustion equipment
- Chemical processing
- Semiconductors
- Industrial motors

Applications for fasteners made from the pure refractory metal can be limited by the atmosphere in which they are to be used. Although all four metals discussed here have a melting point above 2400°C, it should be noted that they are susceptible to oxidation at much lower temperatures, and care should be taken to protect them if necessary. Tungsten oxidises above 190°C, molybdenum above 395°C and tantalum and niobium above 425°C. Of course, in high-temperature vacuum applications or inert atmospheres, this characteristic does not cause a problem. An alternative to shielding them from oxidation is to use a suitable refractory metal alloy. In comparison, stainless steels can be used in oxidising atmospheres up to between 925°C and 1150°C, depending on the grade^[11].

For further information please visit the Goodfellow website at www.goodfellow.com/E/Bolt.html or send an e-mail to info@goodfellow.com.

References

[1] <http://www.goodfellow.com/E/Niobium.html>

[2] <http://www.goodfellow.com/E/Molybdenum.html>

[3] <http://www.goodfellow.com/E/Tantalum.html>

[4] <http://www.goodfellow.com/E/Tungsten.html>

[5] Full size bolts, screws, studs to ASTM F593-91

[6] The code is made up of two numbers separated by a dot. The number to the left of the dot when multiplied by 100 provides an indication of the ULTIMATE STRENGTH in megapascals, while the number to the right when multiplied by 10 times the preceding number gives YIELD STRENGTH (megapascals - MPa) or STRESS at 0.2% PERMANENT SET (MPa) depending on the strength grade.

[7] ASTM B708-05 Standard Specification for Tantalum and Tantalum Alloy Plate, Sheet, and Strip

[8] ASTM B777-07 (2013) Standard Specification for Tungsten Base, High-Density Metal (note this lowest figure is for 97% dense, sintered metal)

[9] Mechanics of Materials, Third SI edition, Gere and Timoshenko, published by Chapman and Hall ISBN 0-412-36880-3

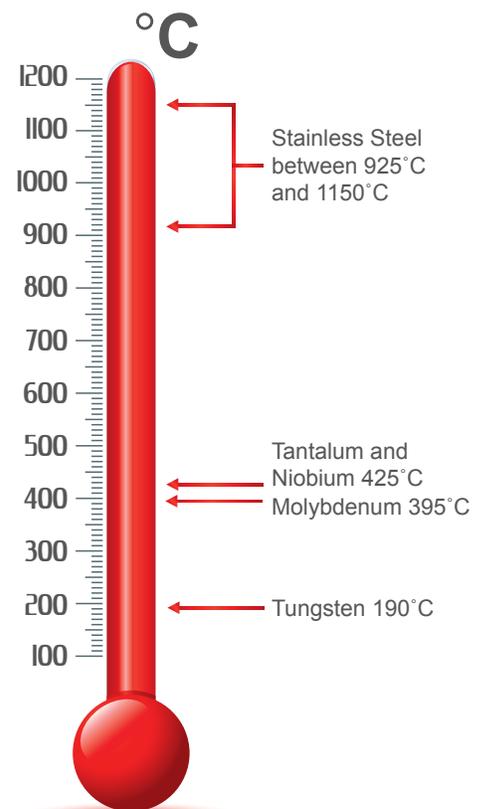
[10] The Engineering Properties of Tungsten and Tungsten Alloys, Schmidt and Ogden, Office of the Director of Defense Research and Engineering, Defense Materials Information Center

[11] <http://www.azom.com/article.aspx?ArticleID=1175>



Refractory metal fasteners can be used in very demanding applications.

Limits for metals/alloys before oxidation occurs*



*Dependent on humidity and atmosphere. Indicative values only.