TUNGSTEN HEAVY ALLOY

Design Manual

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Concluding Remarks

1. The Metallurgy of Tungsten Heavy Alloys

The name "tungsten" is derived from the Swedish term meaning "heavy stone". Tungsten has been assigned the chemical symbol W after its German name *wolfram*. While sometimes regarded as a scarce or exotic metal, its abundance in nature is actually about the same as that of copper. The largest known tungsten reserves are in mainland China, though plentiful reserves also exist in North America.

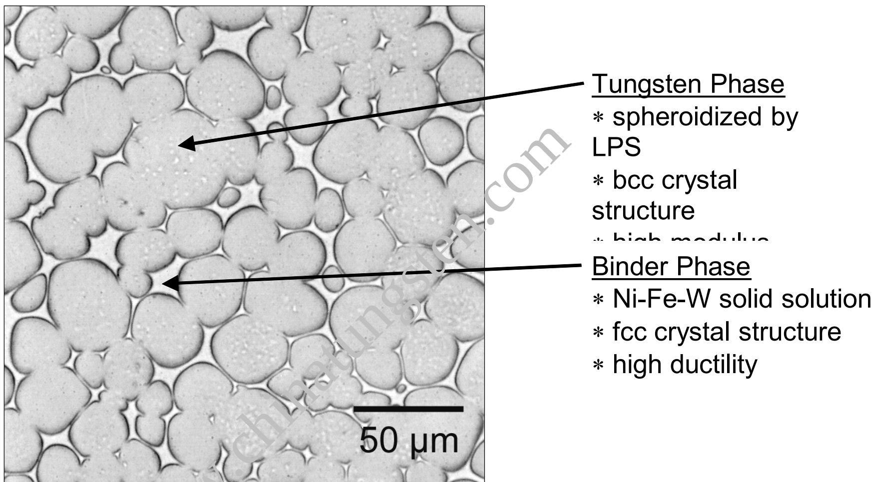
Tungsten has the highest melting point (3410°C or 6170°F) of all metals. The extremely high melting point of pure tungsten makes all the common manufacturing techniques used for metals such as iron impractical. Specialized methods make possible the processing of pure tungsten into rod, sheet, and wire for a wide variety of high temperature applications including incandescent lamp wire, TIG welding electrodes, and high temperature heat shielding.

Another important industrial property of tungsten is its high density of 19.3 g/cc (0.70 lbs/in^3). In addition to high gravimetric density, its high radiographic density makes it an ideal material for shielding or collimating energetic x- and γ-radiation. For such applications, tungsten is commonly alloyed in order to circumvent the extremely high processing temperatures that would otherwise be required to melt and cast the pure metal.

Tungsten heavy alloys (WHAs) are ideally suited to a wide range of density applications, offering a density approaching that of pure tungsten but without the very costly processing and inherent size and shape limitations of the former. WHAs are produced by a powder metallurgy (P/M) technique known as liquid phase sintering (LPS), in which completely dense, fully alloyed parts are formed from pressed metal powders at a temperature less than half the melting point of pure tungsten. While sintered steel and copper alloy parts commonly contain significant residual porosity that may require polymeric infiltrants to seal, sintered WHAs have a nonporous surface.

WHA parts are manufactured from very fine, high purity metal powders – typically tungsten, nickel, and iron. The blended metal powder is compacted under high pressure (up to 30 ksi) to form a specific shape that is very close to the geometry of the final part. By utilizing this near net shape forming approach, economy is realized by the elimination of excess material and the time and energy necessary to remove unwanted stock from mill shapes. Pressed parts are then subjected to high temperature sintering in hydrogen. As the parts are slowly heated, the hydrogen reduces metal oxides present and provides a clean, active surface on each of the very small metal particles. As temperature increases further, chemical diffusion takes place between particles. Neck growth occurs between particles, and surface energy drives pore elimination and part densification. The pressed part shrinks uniformly, with about 20% linear shrinkage (equating to approximately 50% volumetric shrinkage) being typical. Once the temperature is sufficiently high to form the liquid phase, any remaining densification occurs very quickly as the alloy assumes a "spheroidized" microstructure by a mechanism know as Ostwald Ripening. The sintered structure of a common commercial WHA is two-phase, consisting of a linked network of tungsten spheroids contained in the ductile matrix phase.

The spheroidized microstructure shown below is typical for most commercial WHA products. The rounded phase (~30-60 μm in diameter) is essentially pure tungsten, which is surrounded by a metallic nickel-iron binder phase containing some dissolved tungsten. This structure provides the maximum mechanical properties for a given alloy composition. Through the process of pressing and LPS, metal powders are transformed into fully dense shapes that are very close to the dimensions of the finished parts.



WHAs can subsequently be subjected to post sinter heat treatment and mechanical deformation to increase tensile properties and create directional microstructures. While such operations are commonly required for military applications, commercial WHAs generally do not require this additional processing and are supplied in the as-sintered state for maximum economy.

WHAs are a special class of materials, differing from pure tungsten. They share almost no common characteristics with "tungsten steels" (high speed T grade steels). While this manual focuses on standard commercial grade WHAs, it is also possible to provide tungsten-nickel-iron alloys that have:

---Density ranging to 19.0 g/cc
---Tensile elongation up to 35%
---Hardness to HRC 44
---Tensile strength to 200 ksi or greater

Certain size and shape limitations apply when these post-sinter processing steps are required. This design manual has been compiled to convey some of the special characteristics of this family of materials that will be of importance to proper design and use. Only by observing these guidelines can optimum product design, economy, and performance be realized. We at Tungsten Products strive to provide you – the customer – with the best material and most complete technical support available in the industry today.

2. Alloy Selection Criteria

Why Use WHAs?

WHAs provide a unique combination of density, mechanical strength, machinability, corrosion resistance, and economy. Consequently, WHAs are widely used for counterweights, inertial masses, radiation shielding, sporting goods, and ordnance products. These versatile materials provide distinct advantages when compared to alternate high density materials, as seen in the table below.

Material	Density (g/cc)	Tensile Strength	Stiffness	Machin-ability	Toxicity	Radio-activity	Cost
WHA	17.0-19.0	moderate	high	excellent	low	none	moderate
Lead	11.4 max.	very low	very low	very low	high	none	low
Uranium	18.7-18.9	moderate	medium	special	high	present	high

As can be seen from these data, WHA overcomes the toxicity, deformability, and inferior density of lead and its alloys. Likewise, it can provide equivalent density to depleted uranium (DU) but without the special machining considerations (necessary due to its pyrophoricity) and licensing requirements for a radioactive substance. WHA is truly the material of choice for high density applications. These unique alloys provide the designer with many new freedoms.

There is one special category of density applications in which WHAs should not be used. For applications in which the service temperature will exceed ~300°C, slight surface oxidation will occur in air. It is important to note that at service temperatures exceeding ~500°C, WHA strength will fall off rapidly even in a protective atmosphere. For these special cases, pure tungsten may provide a better option. If reactive atmospheres are present in combination with elevated temperature, the best choice for very dense materials will be the platinum group metals – but at extremely high cost.

Density

Density is the single most important property that makes a WHA the material of choice for a given application. The selection of a specific composition for a given density application may ultimately be made on the basis of concurrent mechanical property requirements or sintering considerations, unless a specific value of density is critical. WHAs can approach the density of pure tungsten and DU without the high cost of the former or the licensing and special handling requirements of the latter.

As is true with most mechanical designs, the optimum design is the one that adequately addresses all critical parameters and offers the best compromise of the remaining options. As the density of a WHA is increased, the available ductility decreases. Alloy density varies according to tungsten content, as can be seen in the following table of Tungsten Products standard alloys.

TP Alloy*	Composition (Wt. %)	MIL-T-21014D Classification	Typical Density (g/cc)	Typical Density (lbs/in^2)	Magnetic Permeability (μ)
SD170	90W-(3Ni/Fe)	Class 1	17.14	0.619	>6.0
Dens21	90W-(7Ni/Fe)	Class 1	17.20	0.622	1.02-1.05
SD175	92.5W-(3Ni/Fe)	Class 2	17.62	0.637	4.5-5.0
Dens23	92.5W-(7Ni/Fe)	Class 2	17.66	0.638	1.02-1.05
SD180	95W-(3Ni/Fe)	Class 3	18.13	0.655	4.0-4.5
Dens25	95W-(7Ni/Fe)	Class 3	18.16	0.656	1.01-1.02
SD185	97W-(3Ni/Fe)	Class 4	18.57	0.671	2.5-3.0

In addition to these standard compositions, Tungsten Products can also manufacture custom alloys. Please inquire with any special applications you may have.

Mechanical Properties

Mechanical properties of modern WHAs far surpass those available from WHAs even a few decades ago. Three factors primarily contribute to this advance: (1) higher purity raw materials, (2) cleaner and more precisely controlled process environments, and (3) the use of modern tungsten-nickel-iron (W-Ni-Fe) compositions rather than the older alloys containing copper.

It is also important to note as a general consideration that maximum attainable properties for these alloys varies with the size of the blank. This is a direct consequence of the nature of the sintering operation used to make the parts. A number of gradients – thermal, chemical, and gravitational – exist during sintering. As the maximum section thickness of a given part is increased, thermochemical removal of impurities from the center of the pressed part prior to surface pore closure becomes more difficult. Therefore, small parts will always tend to have higher mechanical properties than larger ones.

Tungsten Products offers a standard set of commercial alloys that conform to MIL-T-21014D, ASTM B777-87, and AMS-7725B requirements for mechanical properties. As seen in the table below, the nominal properties listed meet or exceed these specification requirements. All values shown are for material in the as-sintered state, as this is the most commonly supplied condition of the material for commercial applications.

TP Alloy*	Wt.% W	UTS (ksi)	0.2% YS (ksi)	EL (%)	Elastic Modulus ($x 10^6$ psi)	Hardness (HRC)
SD170	90	120	80	10	45	27

Dens21	90	110	80	8	45	27
SD175	92.5	120	80	6	48	27
Dens23	92.5	110	80	2	48	27
SD180	95	120	75	4	50	28
Dens25	95	119	75	3	50	28
SD185	97	110	75	3	52	28

All WHAs are susceptible to hydrogen embrittlement, which lowers the ductility of the alloy. Tungsten Products can provide alloys in a hydrogen outgassed (vacuum annealed) condition, which in some cases may double the tensile elongation. Further property enhancements are possible through additional post-sinter processing. For structural (load bearing) applications, it is recommended that material be used in the most ductile condition feasible for the given part.

Thermal and Electrical Properties

The properties of WHA are governed by the properties of its principal constituent, tungsten. While properties will vary slightly with tungsten content, binder composition, and microstructure, several properties will be cited for a typical alloy such as SD175. This material will have a thermal conductivity of ~120 W/m-°K and a corresponding electrical conductivity of ~13% IACS. The thermal expansion is very low, with a CTE of ~5.0E-6/°C at 20°C. The specific heat of SD175 is ~0.36 cal/g/°C. While the melting point of pure tungsten is extremely high, WHAs will begin to form a liquid phase when heated in excess of ~1450°C (2642°F). WHAs are not suitable for high temperature applications.

"Mag" versus "Non-Mag"

It is unfortunate that industry literature has described families of "magnetic" and "non-magnetic" WHAs, thus implying significant magnetization of the former. "Magnetic" denotes a reasonable attraction to a magnet – not that the WHA itself behaves as a permanent magnet in the condition supplied. The magnetic response of WHAs is most commonly measured with an instrument such as the *Low Mu Permeability Indicator* (Severn Engineering Co., Annapolis, MD). By governing industry specifications, "non-magnetic" character is defined as a magnetic permeability of 1.05 μ or less – a condition indicated by this tester on a go/no-go basis. This is roughly the same level of magnetic response as that of a typical austenitic stainless steel. A strong neodymium magnet will stick weakly to either material, thus indicating this response is a matter of definition rather than true "either/or" character. As both classes of WHA are electrical conductors, eddy currents can be induced in either one if subjected to an EM field. "Non-magnetic" WHAs are typically used whenever existing (functional) magnetic fields cannot be perturbed in radiation equipment and for certain well logging probes in which the shielding is positioned near electrical sensors or when magnetometer scanning is performed.

Historically, the older tungsten-nickel-copper compositions have been used in these applications. While current "non-mag" tungsten-nickel-iron formulations provide improved mechanical properties, their properties are still lower than those available from "mag" grades. Therefore, unless specifically required by a given application, standard "magnetic" alloys are the better choice.

(* listed alloy characteristics are for reference only and subject to change without notice)

3. Design Considerations

Powder metallurgy (P/M) offers two options for WHA manufacturing – near net shape blanks or net shape parts. These considerations apply as well to P/M parts of materials such as copper and steel as well. Further, the specific nature of WHA presents additional considerations that must taken into account in the design process.

The Nature and Advantages of P/M

P/M is a very useful modern manufacturing process that provides a means of producing parts from blended metal powders that circumvents the need to start with larger than needed mill shapes and then spend money and time removing excess stock. Through P/M, individual parts can sometimes be made (net shape) without any machining in the following series of steps:

POWDER → PRESS → SINTER

This sequence is typically limited to smaller parts that have no significant angular features, thin walls, extreme dimensions, webs, steps, or undercuts. Consistent press density in such parts must be maintained so as to create uniform shrinkage in sintering. Parts are typically compacted in a uniaxial hydraulic press, and may necessitate the use of an organic binder that is removed prior to sintering. A slight relief angle on vertical sides is also useful to aid in damage-free part release and ejection from the pressing die. This fabrication route provides the best economy. Under certain conditions, sintered dimensions can be held to 0.5% or better. P/M favors the production of blank shapes with reasonably uniform dimensions. Therefore, extreme combinations such as large area/minimal thickness, small horizontal section/deep fill, and significant front to back geometry differences should likewise be avoided in the design phase if this simplified fabrication approach is desired.

Most parts however, by nature of size or geometric complexity, require some secondary machining and are fabricated as near net shape blanks as follows:

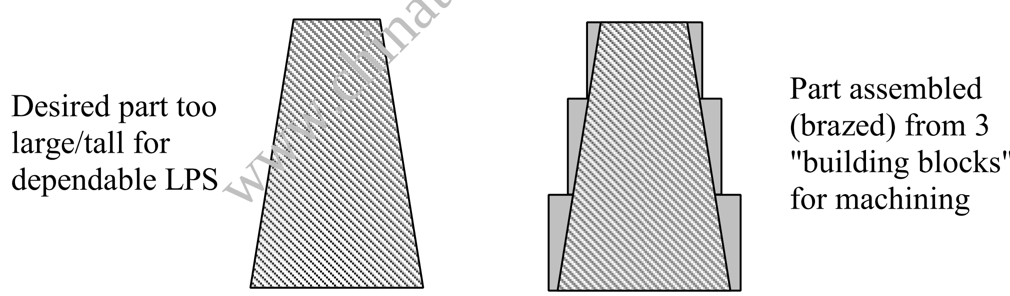
POWDER → PRESS → SINTER → MACHINE

This approach is mandatory for components containing angular features and steps and for simple shapes with very tight dimensional requirements. It is important to keep in mind for parts of critical weight and tight tolerance that some provision be made for weight adjustment to compensate for slight variations in density from nominal values on a per-piece basis. Additional constraints may apply when post-sinter processing is required.

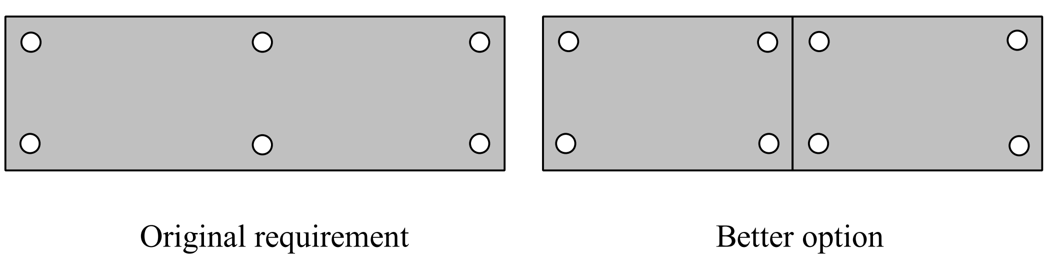
During high temperature LPS, gravity tends to distort or "slump" parts. This behavior becomes more prominent the greater the part height is with respect to the basal area. Higher %W alloys should be used for greater slump resistance. For many applications, due to these P/M considerations, a 92.5%W alloy will be a good choice.

Single Piece or Multi-Part?

While conventional wisdom holds that there is economy in size, this philosophy has a limit when applied to P/M. As part size increases, attainable mechanical properties decrease slightly. Large parts also invite the formation of a front to back density gradient, especially in lower %W alloys. Also, as part size increases, machining allowances must also be increased to guarantee clean up of the blank to the finished geometry. Very tall parts would prove impractical to make as a single piece because of furnace height limitations and tendency for gravitation collapse during LPS.



The solution for large or special geometry parts is to fabricate them as smaller "building blocks" which can either be mechanically fastened to supporting structures or furnace brazed into a large monolithic component and then machined. The building block approach also makes possible the creation of functionally gradient materials when utilized in furnace brazed or sinter bonded assemblies.

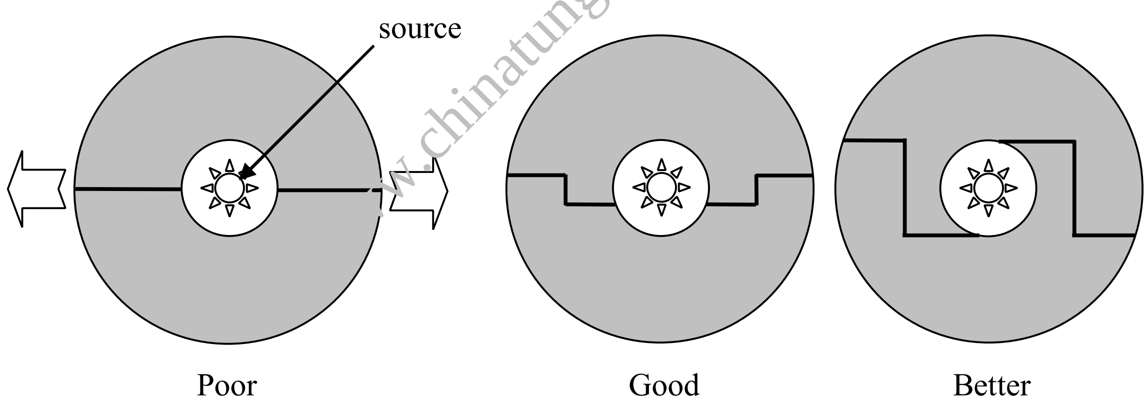


Making a large weight component as a series of smaller, mechanically attached ones overcomes manufacturing size limitations and can result in better mechanical properties and more economical parts that if damaged in service, can be replaced by section as needed rather than as a whole.

Tungsten Products currently offers 7 standard grades of WHA in a variety of block, flat, and round shapes – or custom machined to final form. Sizes can range from gram weight to many hundreds of kilograms. Sheet is available in thicknesses down to 0.025".

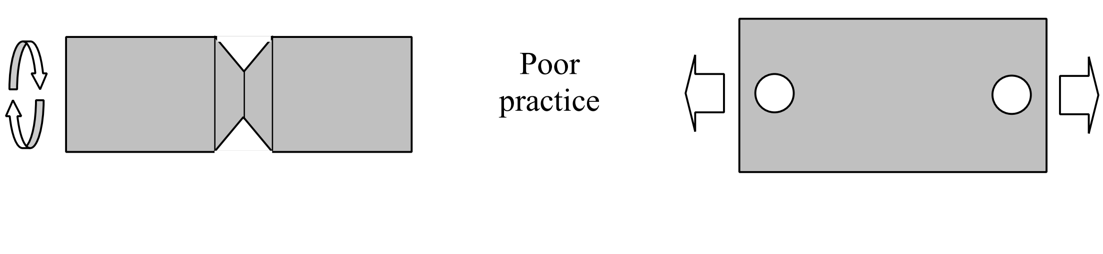
"Radiation Joints"

Many cylindrical shaped radioisotope containers having noncircular radial windows would be virtually impossible to manufacture as a single piece, as it would be extremely difficult to devise a method to EDM the aperture and preserve any sharp angular definition. The solution is to employ Tungsten Products "radiation joint" construction, which prevents any possibility of straight line of sight radiation leakage by means of geometric offsets in the mating halves. As seen in the transverse cross sectional diagrams below, even very carefully machined flat joints can allow some radiation penetration. By use of a simple step, the risk of direct line leakage from the contained source is eliminated. A more elaborate joint with larger offsets that further reduces radial features may be justified in some applications. Securing hardware such as bolts can be also made of WHA to preserve protection level.



Preserving Maximum Mechanical Strength

Good mechanical designs avoid unnecessary stress concentration. This is especially important considering the notch sensitivity of all WHAs. Attention to details such as the sharpness of internal corners, root radii of notches, grooves and threads, and the proximity of holes or other cutouts to part edges help preserve the maximum attainable strength from a WHA part. Concave radii should be limited to 0.020" or greater whenever possible. Holes should not be located closer than 1.5 times hole diameter from the edge of a part. While most weights are required to support only low acceleration centrifugal or inertial loads, these strength of materials considerations become even more important in parts that also serve a structural function or are utilized in high speed applications.



4. Machining Guidelines

A principal advantage of WHAs over pure tungsten for density applications is their ability to be readily machined into complex geometries using common metalcutting tools and techniques. While it is generally said that WHAs machine similar to gray cast iron, this description can be misleading. Lower %W alloys with high ductility tend to machine more like a stainless steel of comparable hardness. Due to the high elastic stiffness of WHAs, cutting forces will be higher than for most metals. Rigid tooling and adequate spindle torque are mandatory for good results. Coolant/lubricants, if employed, should be the non-alkaline, water soluble type.

Sawing

Blanks of WHA may be readily cut using a heavy duty shop bandsaw equipped with either a bi-metal blade with hook profile teeth or a segmented edge carbide blade at low speed (100-250 sfm). Coolant is not required for bandsaw sectioning. WHAs may also be cut on an abrasive saw using alumina or silicon carbide blades with coolant.

Grinding

WHAs are capable of excellent surface finishes when centerless or surface ground. Vitrified bond alumina or silicon carbide wheels of medium hardness are recommended. A water soluble coolant should be used. Diamond wheels should not be used due to rapid loading. Surface grinding of very thin stock should be performed carefully so as to avoid bowing from introduced residual stress.

Milling

Virtually all commercial WHAs easily form short chips when machined. The exception to this rule is low %W alloys supplied in a very ductile state, in which case chipbreaking must be addressed in tooling selection. Milling of WHAs is best performed using multi-insert cutter heads. The use of coolant/lubricant is optional.

Roughing

ISO Carbide Grade	Rake (°)	Clearance (°)	Edge Tolerance	Tooth Load (in)	Depth of Cut (in)	Speed (sfm)

K15 or K20	-7° to 0°	0°	G	0.005-0.015	0.030-0.125	200-400

Finishing

ISO Carbide Grade	Rake (°)	Clearance (°)	Edge Tolerance	Tooth Load (in)	Depth of Cut (in)	Speed (sfm)
K15 or K20	0° to +7°	0° to -11°	G	0.003-0.010	0.005-0.030	300-500

Some modern cutter/insert combinations will permit depths of cut on roughing to exceed 0.25" on machines of sufficient power. Best final surface finish is promoted by the use of large nose radius inserts, high spindle speeds, light feed rates, and positive rake inserts. While coated inserts offer improved life when machining most metals, this advantage is sometimes offset when machining WHAs due to the higher cutting forces created by the rounded (honed) edges necessary for coating of the insert.

Turning/Facing/Boring

While HSS cutting tools can be used, optimum performance will be realized through the use of sharp edged carbide inserts. If chatter occurs with longer extensions, toolholders fabricated from WHA provide the best solution to the problem.

Roughing

ISO Carbide Grade	Rake (°)	Clearance (°)	Edge Tolerance	Feed Rate (ipr)	Depth of Cut (in)	Speed (sfm)
K15 or K20	-7° to 0°	0°	G	0.005-0.020	0.030-0.125	200-350

Finishing

ISO Carbide Grade	Rake (°)	Clearance (°)	Edge Tolerance	Feed Rate (ipr)	Depth of Cut (in)	Speed (sfm)
K15 or K20	0° to 7°	7°-11°	G	0.005-0.010	0.005-0.015	250-400

Optimal insert geometry for both turning and milling will be determined by the specific application. Diamond shapes from 35-80° all work well, with larger angles providing more durable cutting edges and also offering the possibility of using the complementary angle corners as well. Hexagonal inserts provide further economy with 6 usable cutting edges but are restricted from machining narrow features.

Drilling

Standard surface treated HSS twist drill bits generally perform satisfactorily. Very high %W alloys or special high hardness WHAs may mandate the use of carbide bits. As hole size decreases, attention to clearance and debris removal become more critical to avoid seizing or breakage. The use of tapping lubricant is recommended.

Tapping

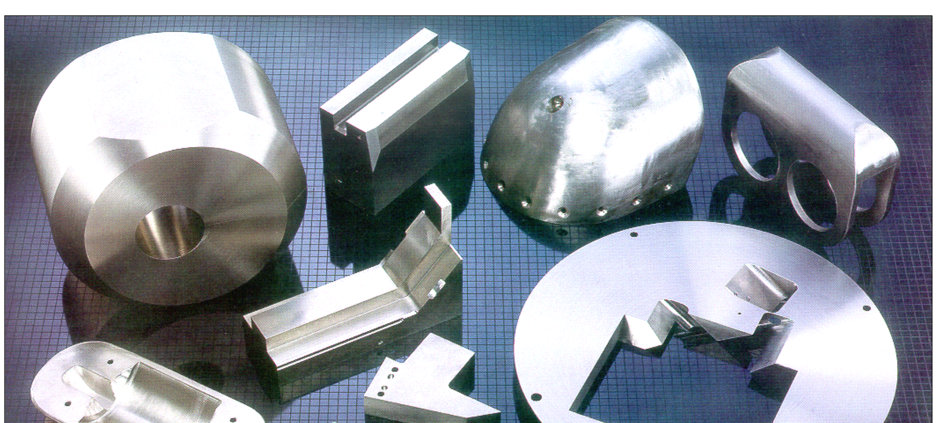
Tapping can be the most challenging operation for WHAs due to the high resultant torque on the tap shank. For this reason, 2 or 3 flute, positive rake, spiral point, high clearance taps should be used. Premium cobalt steel taps perform best for this application. The use of tapping compound (such as a heavy sulfonated oil) is essential. Choose the coarsest thread possible for a given diameter and application. Holes should be tapped to completion without back treading to avoid binding. With care, threads as fine as 2-56 can be successfully tapped. It is generally best to tap large holes with a single point tool. For other difficult to tap situations, the use of a slightly larger pilot hole may solve the problem but with reduced thread engagement area.

EDM Shaping

EDM, both wire and sinker types, are routinely used to shape WHA blanks. EDM should, however, be a "last resort" technique for several reasons. First, it is inefficient compared to metalcutting alternatives. WHAs have high arc erosion resistance, and are occasionally used as EDM tools. EDM shaping is therefore very slow. Also, even at lower spark energy settings, EDM can still introduce surface layer damage that can in some applications prove detrimental. Using EDM to shape highly ductile WHAs can sometimes embrittle them through reintroduction of hydrogen into the metal. Still, EDM remains the only practical shaping technique in some specific applications. An example is the machining of blind, non-circular holes with relatively sharp corners and taper.

Thermal Contouring

Techniques such as oxyfuel, plasma jet, and laser cutting are not recommended for WHAs. These methods typically produce unacceptable levels of oxidation and typically produce localized thermal cracking.



5. Joining

WHA can readily be joined to itself or other materials. Whenever feasible, mechanical methods of attachment are preferred, as they avoid possible thermochemical alteration and its effect on local mechanical properties.

Mechanical

Joining is most commonly performed using standard fasteners such as bolts and pins. WHA parts can be likewise be threaded to perform as fasteners (in such applications as radiation shielding). In choosing a mechanical joining method, it is important to keep in mind the notch sensitivity, impact sensitivity, and low CTE of WHAs. Threads should have as generous a root radius as possible for maximum strength. Impact fastening techniques such as riveting are not recommended. Shrink fitting is possible provided the WHA part is the inner member. For shrink fitting, an interference fit of ~0.005" per side is prepared and the WHA part cooled in dry ice or LN_2 while the outer member is heated to several hundred degrees before fit up.

Brazing

Brazing is best performed in a hydrogen furnace to protect the WHA part from oxidation. A variety of filler metals such as pure copper, monel, and standard brazing alloys based on copper, silver, and/or nickel can be used. Brazing temperature constraints and the end application generally determine the filler metal choice. Large components can be assembled from a number of smaller pieces using this approach. As with any brazing operation, good joint preparation is essential for producing fully bonded interfaces. Clearances of ~0.002" or less are typical. Brazing can alter the chemistry within the immediate vicinity of the joint. Points of attachment should not be located along such zones. Manual torch brazing using a flux is also possible but will result in oxidation and is limited to joining smaller components. Low temperature solders will not wet WHAs.

Welding

Welding is generally not performed on WHAs due to the vast difference in melting point between the W phase and binder phase. A TIG (GTA) torch can however be used as a very intense heat source to flow fillers such as monel, pure nickel, or nickel-based superalloys into a joint for a "quasi-weld". This technique requires much experience for good results.

Sinter Bonding

This is a technique that is typically limited to joining parts at the time of manufacture to form larger assemblies. Performed in a hydrogen furnace at the LPS temperature, sinter bonding results in an invisible interface with no local degradation in mechanical properties.

6. Finishing

WHAs are reasonably resistant to corrosion and are not susceptible to stress corrosion cracking (SCC) as is a competitive high density material, DU. For some density applications such as aircraft counterbalance weights, long term corrosion resistance becomes a concern due to persistent exposure to harsh environments. In such cases, a variety of protective finishes can be applied. While relatively resistant to corrosion under ambient conditions, extreme humidity, salt spray, and the presence of strong electrolytes can prompt surface corrosion. This is due to the electrochemical difference between the matrix and the tungsten phases, which sets up micro-scale galvanic cells on the exposed surface. The matrix phase is most readily attacked by acidic solutions, whereas the tungsten phase is most rapidly dissolved by alkaline solutions. WHAs are not generally used in marine applications, but should have a protective coating for any such use.

It is important to note that certain conversion coatings (black oxide, chromate, phosphate, etc.) though in widespread industrial use, are not suitable for WHAs. As an example, the chemistry of black oxide processes for steels is based on the presence of an iron-rich surface, which is definitely not the case for any commercial WHA. Therefore, if such a technique is utilized, the expected appearance and durability of oxide coating on WHA will not be achieved. Similarly, anodizing processes which are widely used for aluminum and reactive metals are not appropriate for WHAs, which by nature do not form the same type of coherent surface oxide layer.

Conversely, when a uniform chemical attack is desirable (such as for decorative etching, marking, or chemical machining), the same electrochemical differences between the two phases comprising WHA prevents consistency of dissolution response. While basic marking can be done chemically, it will not be uniform on a microscopic scale. If high definition, solvent resistant patterns or ID markings are required on WHA parts, it is recommended that either vibratory scribe or laser marking systems be employed.

Metallic

Cadmium plating with a chromate overcoat is commonly used for aircraft weights. This type of plating is ideal should the coating need to be periodically stripped. For more durable and less toxic protective coatings, nickel is an excellent choice. Alkaline plating solutions should be used to avoid hydrogen introduction into highly ductile parts.

Organic

A variety of polymeric finishes, including epoxy and acrylic based, may be effectively used. Organic coatings are probably the best choice in most applications. Paints additionally allow convenient color coding and ID marking of components when required. Organic coatings also provide a dielectric layer, useful in preventing the formation of a galvanic couple when WHA weights are fastened to dissimilar metals such as aluminum alloys. For optimum durability, organic coatings should be dried by baking at the recommended temperature to ensure the full set of curing reactions occur.

7. Typical Applications

Radiation Shielding

Modern industrial radiography and oncology systems currently utilize beam energies that can exceed 2 MeV from isotopic sources and well over 20 MeV from small accelerators. The absorption behavior of WHAs for high energy electromagnetic radiation is derived from the high linear absorption coefficient of the principal tungsten phase. These alloys are excellent materials for the shielding and collimation of x-and γ-radiation due to their combination of radiographic density, machinability, strength, and low toxicity. WHAs offer a superior protection level to lead in an equivalent thickness. But unlike lead, WHAs resist deformation and can be accurately fastened – important factors in the construction of multi-leaf radiation collimators. WHA can be supplied in the form of thin rolled and machined sheet for such applications. For bulk shielding applications, Tungsten Products has manufactured many shielding components in the 100-1000 kg size range. Large isotope containers can be fabricated with complex geometry radial beam ports using "radiation joint" construction. Class 2, 3, or 4 WHAs are typically used for shielding.

Aircraft Counterbalances

Counterbalance weights for fixed and rotary wing aircraft have been used for many years. WHA weights, unlike lead which creeps under its own weight at room temperature, can be securely fastened to aerostructures. In contrast to DU weights, WHA weights are free from SCC concerns, special licensing requirements, environmental issues, and the negative public response to having many pounds of radioactive material routinely flying overhead. WHA weights are typically machined from near net shape blanks to precise tolerances and provided with a protective coating to the customer's specification. This is an application where a coating is highly recommended to resist corrosion from temperature and moisture cycling, de-icing fluids, aggressive aircraft cleaning fluids, and galvanic contact with fasteners and the airframe. Class 1 or 2 WHAs are most commonly used.

Well Logging

WHA is an excellent casing material for down hole logging of oil wells. Casings must be sufficiently heavy to readily sink through materials such as barite mud and strong enough to withstand the hydrostatic pressure of this harsh environment. Most designs are highly machined for sensor and window positioning. Mechanical properties are very significant to the survivability of these rather large components. Tungsten Products has years of experience in producing high properties in large bars of class 1, 2, or 3 material.

Racing Weights

Drivers consistently report they can sense differences in how a car handles on the track if the weight on a given wheel varies only by a couple of pounds. Fine tuning a car to a given track is a very cumbersome and time consuming ordeal with conventional lead plate weights. WHA weight blocks offer up to 50% more weight in a given volume, with the added advantages of direct attachment via threaded holes or thru-bolting and the freedom from deformation that is a constant problem with lead. Class 1 or 2 WHAs are most commonly used. The high density of WHAs permit weights to be placed in the lower half of NASCAR weight adjustment tubes, effectively lowering the overall center of gravity for improved handling. Tungsten Products has a specialized line of racing weights for these applications.

Boring Bars

The high density, high elastic (Young's) modulus, and composite microstructure of WHAs make them ideal materials for low chatter boring bars and long extension toolholders of various types. WHAs are very stiff and resistant to deflection. Their high density, coupled with the two phase microstructure of the alloy, provide effective vibration attenuation. Class 1 or 2 WHAs are most commonly used.

Ordnance Applications

WHAs have been routinely used in high density fragmenting devices and armor piercing (AP) ammunition ranging from small caliber 5.56 mm rounds up to 120 mm anti-tank projectiles and beyond. Material for kinetic energy penetrators is typically vacuum annealed and resolutionized/quenched for maximum ductility (25-35% EL typical) and toughness prior to being cold worked by swaging. Deformation processing generates a directional microstructure, high yield strength (150-200 ksi for most designs), and elevated hardness (40-44 HRC). Even higher mechanical properties are attainable from tungsten-nickel-cobalt compositions. These high property sets provide a useful indication of the wide range of properties in which WHAs can be supplied.

Concluding Comments

We hope that this WHA Design Manual has proven both useful and interesting. WHAs provide an extremely versatile property set to design engineers, and we at Tungsten Products strive to be the industry leader not only in supplying the highest performance alloys, but also the best customer and technical support available. Our ISO 9002 certification stands as proof of our commitment to quality. Whether your application is best addressed with standard alloys or a completely custom product, we welcome your specific inquiries.

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