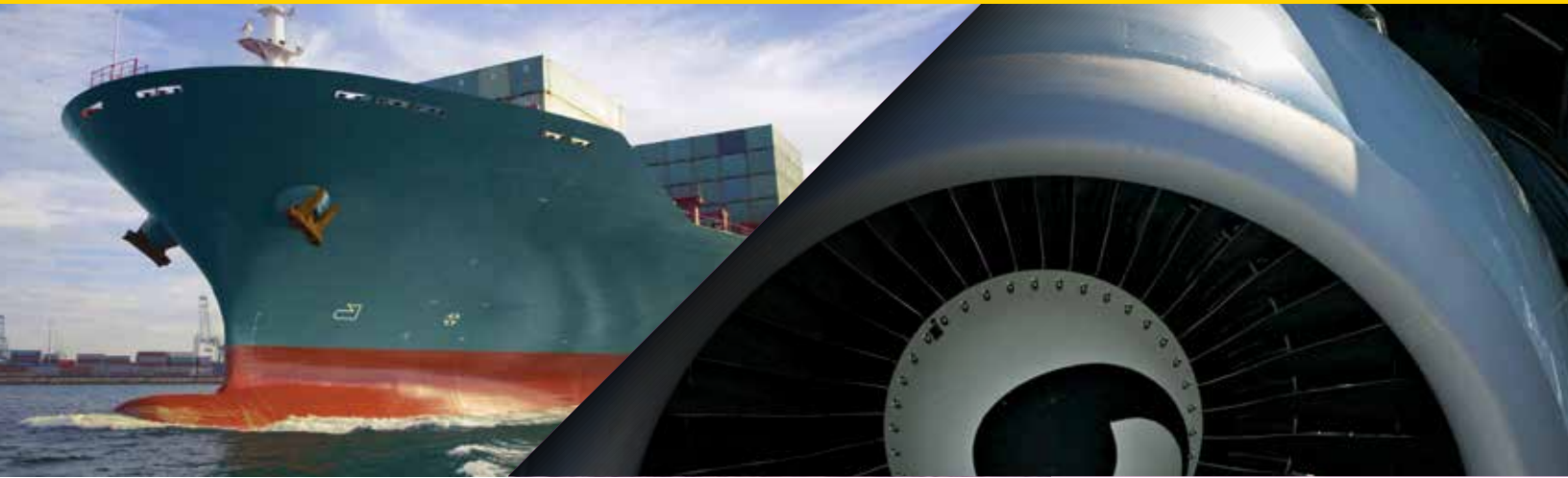


DENSALLOY

Tungsten Heavy Alloy



TUNGSTEN HEAVY ALLOY

Celebrating more than 75 years as an industrial technology leader, Kennametal Inc. delivers productivity to customers seeking peak performance in demanding environments. The company provides innovative wear-resistant products, application engineering and services backed by advanced material science, serving customers in 60 countries across diverse sectors of aerospace, earthworks, energy, industrial production, transportation and infrastructure.

Kennametal's broad and innovative custom solutions are derived from advanced materials sciences, application knowledge, design expertise, customer support, and commitment to a sustainable environment.

These solutions are all developed to customer requirements:

- **Fabricated and assembled engineered components for wear applications, balance weights, vibration damping, and radiation shielding.**
- **Earth cutting technologies for underground and surface mining and construction products.**
- **Surface technologies such as wear- and corrosion-resistant coatings, claddings, and plates for challenging applications.**





General Characteristics

Kennametal Densalloy™ tungsten heavy alloy (WHA) offers a unique combination of engineering properties; a tensile property set similar to many medium carbon steels, good corrosion resistance, and is easily machinable with common shop tools and techniques.

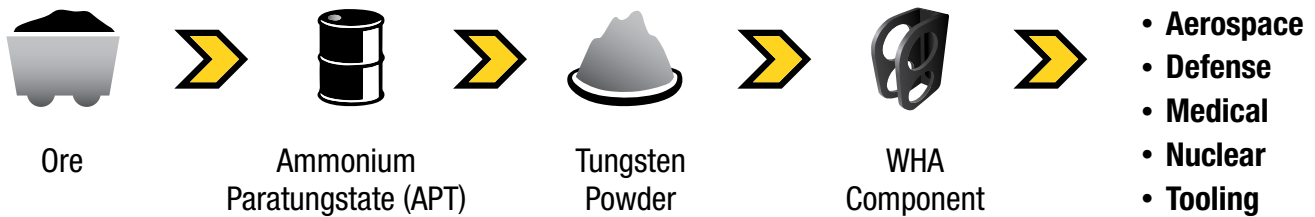
Kennametal Densalloy™ tungsten heavy alloy is readily available in a wide range of sizes and forms. The most significant characteristic, however, is that it offers high density in an affordable material. High gravimetric and radiographic density result in its use in a wide spectrum of mass property and (high energy photonic) radiation shielding applications. Even the lowest Tungsten (W) content grade is over 150% the density of pure Lead (Pb). Unlike Pb alloys Kennametal Densalloy™ alloy is both mechanically strong and of low toxicity, making it an ideal, environmentally friendly substitutes for Pb and Depleted Uranium (DU)-based alloys in a number of medical, industrial, power generation, and defense applications. The optimum grade for a given application is chosen based on the best match of manufacturing and metallurgical characteristics to the service requirements.



Counter Weights

Heavy Alloy Manufacturing Process

Kennametal is a vertically integrated producer of tungsten heavy alloy components, we control the manufacturing process from ore to powder to finished product.



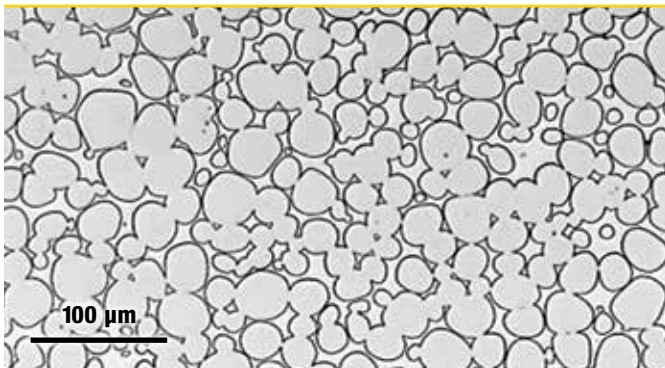
Tungsten Powder Production

Tungsten powder is initially made from tungsten ore (Wolframite/Scheelite), which is chemically processed into Ammonium Paratungstate (APT). APT is then converted into tungsten oxide and subsequently reduced to pure tungsten powder. The tungsten powder is then mixed with the alloying powders to produce a homogeneous blend of Densalloy™. Each lot of powder is then reviewed and tested to ensure prescribed metallurgical properties have been achieved.

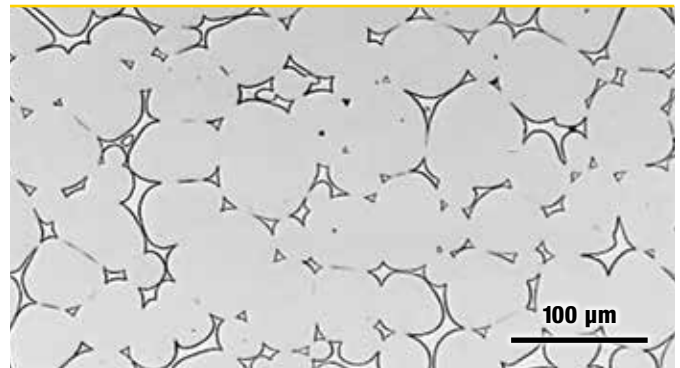
Pressing

We employ a variety of technologies that are used to cold press the Densalloy™ powder into green compacts. These technologies include dry and wet bag isostatic presses, as well as uniaxial presses ranging in capacity from 15 – 1,000 tons. Size, quantity and component complexity are the main factors in determining which pressing process we use. When a product is large or complex we will press a billet of compacted powder and use green shaping process to produce a near-net-shape preform.

Typical Appearance of Class 1 WHA



Comparative Image of a Polished Class 4 WHA





Green Shaping

A variety of methods may be used to shape green compacts prior to sintering. Green shaping allows us to produce near-net-shape components that are too large or complex for traditional press and sinter processes, or when low quantities are required. Thereby optimizing manufacturing efficiencies and reducing machining of the final product.

Sintering

Sintering Densalloy™ is accomplished by a sintering process in closely controlled furnaces at temperatures between 2500 – 3000°F. Sintered material can then be machined by a variety of conventional methods.

Machining

We have a wide range of advanced CNC turning and milling centers, wire EDM, centerless grinders, as well as access to processes such as plunge EDM, metal stamping, gun drilling, double disc and blanchard grinding. We have both hot and cold rolling mills with the capability to roll tungsten heavy alloy sheet to a thickness of 0.020 inch. All of these capabilities equip us with the flexibility to satisfy the most demanding jobs regardless of size.



Vibration Dampening Weight

Technical/Engineering Information

To help enhance our customers' design process and reduce cost, we have experienced design and application engineers ready and available to discuss material selection, blank configuration, and machining recommendations.

Engineering Services

Kennametal has a wide variety of design and solid modeling capabilities for concept evaluation, mass property calculation, and complex machining. With our systems we can also link directly to our customers through their own specific design systems.

Machining Guidelines

Densalloy™ is similar to machining gray cast iron due to its high abrasiveness and the discontinuous chips produced when machining this material. Tungsten carbide tools are used for milling, turning and drilling; however, cobalt steel is recommended for tapping. Either dry or the use of water soluble emulsion coolants during turning and drilling operations is acceptable but for milling the suggestion is not to use coolant. For grinding the use of water soluble emulsion is best. Cutting speeds should be in the range of 100 – 300 SFPM, and feeds should be set to maintain approximately a 0.006 – 0.010 inch chip load. Depth of cuts for roughing can be as much as 0.125 inch and for finishing up to 0.030 inch.

Fastening and Joining

Densalloy™ can be joined to itself and other materials using brazing and conventional mechanical methods. Brazing is most effectively done using nickel or copper in a reducing atmosphere.

Densalloy™ can also be very effectively joined to itself using a diffusion bonding process. Diffusion bonding causes diffusion of sintered Densalloy™ material across the joint interface resulting in an almost indiscernible joint in the finished part.

Finishes – Corrosion Resistance

Although Densalloy™ possesses relatively good corrosion resistance, slight corrosion will occur in high humidity atmospheres. Various finishes can be applied to improve its corrosion resistance. This includes cadmium and nickel plating, as well as acrylic and epoxy paints.



Applications

Densalloy™ products are offered as machinable blanks or as finished parts, precision-machined to the customer's specifications and used in many different applications, as indicated below.

Bar and Sheet Stock

ROTF (Rough Oversize to Finish) Blanks

Counterbalance Weights/Vibration Dampening

Defense Related Product

Industrial Applications

- Aircraft control surfaces
- Helicopter rotor systems
- Ship ballasts
- Crankshaft balancing
- Turbine balancing
- Racing chassis weights
- Gyroscope rotors
- Inertial energy storage systems

Radiation Shielding Components

- Nuclear testing equipment
- X-ray apparatus, e.g. shielding parts in radiation therapies
- Nuclear energy and its applications
- Storage of energetic radiation emitters
- Collimators
- Shielding blocks
- Oil well logging instrumentation

Industrial Tooling

- Boring bars
- Toolholders with long overhangs
- Shanks for grooving tools and carbide inserts
- Grinding spindles and turning spindles
- Turning and milling draw-in arbors
- Disk-blade holders for gear-shaping machines
- Extension shanks
- Reamer holders

Standard Kennametal WHA Grades

Grade	Nom. Composition (wt.%)	AMS-T-21014	ASTM B777-07	AMS 7725E	Characteristics and Applications
W80K	80W-20Cu	N/A	N/A	N/A	Infiltrated electrode material for EDM, welding, switchgear.
SD170	90.0W-7.1Ni-2.9Fe	Class 1	Class 1	Class 1, Type 2	Maximum WHA ductility and formability – ideal for many mass property uses such as aerospace counterweights.
X90	90.0W-7.5Ni-2.5Cu	Class 1	Class 1	Class 1, Type 1	WHA grade offering the lowest magnetic permeability.
DENS21	90.0W-8.8Ni-1.2Fe	Class 1	Class 1	Class 1, Type 1	Provides ductility with low magnetic permeability.
E91	91.0W-6.0Ni-3.0Fe	N/A	N/A	N/A	Ordnance uses such as long rod penetrators.
E915	91.5W-5.7Ni-2.8Fe	N/A	N/A	N/A	Ordnance uses such as long rod penetrators.
SD175	92.5W-5.4Ni-2.1Fe	Class 2	Class 2	Class 2, Type 2	General purpose WHA grade, excellent choice for high stiffness tool holders.
E925	92.5W-5.0Ni-2.5Fe	Class 2	Class 2	Class 2, Type 2	General purpose WHA grade.
DENS23	92.5W-6.6Ni-0.9Fe	Class 2	Class 2	Class 2, Type 1	Low magnetic permeability – ideal for radiation shielding in high energy electron optical systems.
E93	93.0W-4.6Ni-2.4Fe	N/A	N/A	N/A	Ideal for ordnance applications such as long rod penetrators.
SD180	95.0W-3.6Ni-1.4Fe	Class 3	Class 3	Class 3, Type 2	Ideal for both fixed and mobile radiation shielding.
E95	95.0W-3.4Ni-1.6Fe	Class 3	Class 3	Class 3, Type 2	Ordnance applications such as short rod penetrators.
DENS25	95.0W-4.4Ni-0.6Fe	Class 3	Class 3	Class 3, Type 1	Highest density in a low magnetic permeability WHA.
SD185	97.0W-2.1Ni-0.9Fe	Class 4	Class 4	Class 4, Type 2	Maximum attenuation radiation shielding.
E97	97.0W-2.0Ni-1.0Fe	Class 4	Class 4	Class 4, Type 2	Maximum density for WHA ordnance; approximates the density of DU-0.75Ti.

In addition to the standard grades listed above, Kennametal can also provide custom alloys to meet the needs of highly specialized applications. WHA for commercial applications is most commonly supplied in the as-sintered condition, though enhanced property material can also be provided.

Please see the Tungsten Heavy Alloy Engineering Guide (B-14-03925) for further detail.

As-sintered Properties of Kennametal WHA Grades

Grade	Typ. Dens. (g/cc)	Magnetic Perm.	Hardness, typ. (HV10)*	Young's Modulus (GPa)	UTS, min. (MPa)	0.2% offset YS, min. (MPa)	EL, min. (% 25 mm gauge)
W80K	15.6	~1.00	230	230	400	–	–
SD170	17.0	>1.05	280	340	800	540	5
X90**	17.0	~1.00	300	340	850	600	6
DENS21	17.0	~1.01	280	340	800	540	2
E91**	17.3	>1.05	285	350	870	600	22
E915**	17.4	>1.05	285	355	870	600	22
SD175	17.5	>1.05	290	360	800	540	5
E925**	17.5	>1.05	290	360	870	600	22
DENS23	17.5	~1.01	290	360	800	540	2
E93**	17.7	>1.05	295	360	870	600	22
SD180	18.0	>1.05.	300	375	750	540	3
E95**	18.0	>1.05.	300	375	850	600	12
DENS25	18.0	~1.01	300	375	750	540	2
SD185	18.5	>1.05	310	390	700	540	2
E97**	18.5	>1.05	310	390	750	620	8

*HV10↔HRC conversion performed per Table 1 of ASTM E140.

**Hydrogen outgassed properties shown.

Attainable mechanical properties (especially ductility) for a given alloy vary with both part size and sampling location. The ductility of sintered WHA can be increased by post-sinter heat treatment. For example, while shown as having a minimum 5%EL, grade SD170 can be processed to a ductility of 30%EL or greater. Additionally, the strength and hardness of WHA can be increased by deformation processing. Ultimate strengths of 1350 MPa are achievable in many alloys with an associated hardness of ~450 (HV10). With such processing, the yield strength closely approaches that of the ultimate. Please contact Kennametal to discuss your specific requirements.

Please see the Tungsten Heavy Alloy Engineering Guide (B-14-03925) for further detail.



Quality Assurance

Kennametal embraces a commitment to total customer satisfaction. Our knowledgeable employees work hard to deliver high-performance products that conform to customer requirements through quality assurance processes that are complete and compliant.

Our quality department's services are shared throughout the company to insure product compliance at all stages of the manufacturing process. We originate and distribute quality manuals, operating procedures and work instructions based on ISO 9000 standards. Quality department personnel use advanced computerized techniques to perform statistical trend analyses to track, correct and prevent non-conformance during manufacturing operations. We begin by testing each powder lot to verify its density, tensile strength, elongation and hardness.

Photomicrographs are utilized to check for grain structure. State-of-the-art inspection equipment, such as optical comparators and coordinate measurement machines, offer three-dimensional inspection of close tolerance and complex geometric shapes.



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