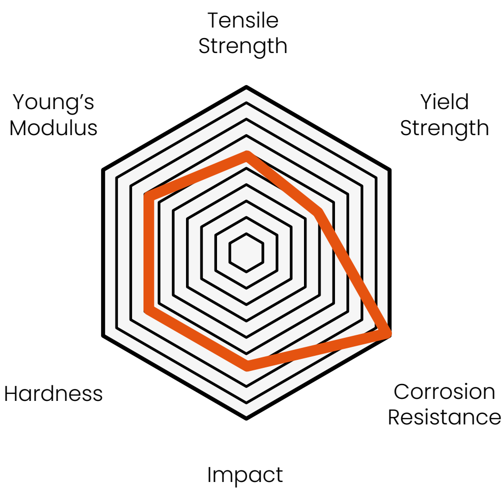
CAL WROUGHT CNC-1®

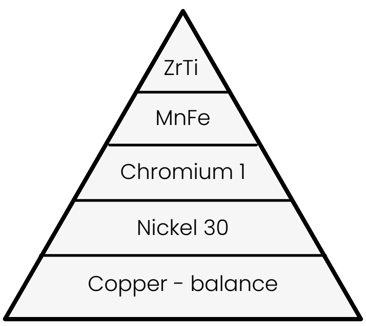
COPPER ALLOYS + ELITE MARINE®

- Extreme shock resistance and safety rating
- High strength combined with extremely high toughness and good ductility
- Outstanding sea water corrosion resistance, comparable to Titanium
- Naturally anti-biofouling

COMBINATION OF PROPERTIES



COMPOSITION %



THE BENEFITS OF CAL WROUGHT IRON

- High mechanical strength and ductility
- Extremely high toughness ~100J higher than NAB and double that of cast CNC
- Extremely high shock resistance
- Outstanding resistance to sea water corrosion both general and pitting corrosion
- Lack of selective phase corrosion (SPC)
- Immune to Hydrogen embrittlement and stress corrosion cracking in sea water
- High resistance to impingement/erosion/cavitation/ pitting in sea water
- Good resistance to stress corrosion cracking in Hydrogen Sulphide conditions
- Anti-biofouling (immune to marine growth)
- High Modulus of Elasticity compared with other copper-based alloys
- Low relative magnetic permeability - virtually non-magnetic
- Easily machined to a high surface finish and dimensionally stable
- Non-sparking
- Uniform fine grain structure permits volumetric inspection using ultrasonic techniques

PHYSICAL PROPERTIES

The main mechanical property headlines for wrought CNC are the high strength and ductility combined with extremely high impact strength and shock resistance. Izod impact strength is around three-times or 100J (74 ft lbf) higher than forged Nickel Aluminium Bronze to Def Stan 02-833 and around double that reported for cast CNC. This important feature can be guaranteed (see Table 3 below) and measured and reported for each batch of material.

Wrought CNC available in two property conditions:

CAL CNC-1: The standard material applicable to all product forms and sizes

All mechanical test specimens used for acceptance testing are integral to the forgings or bars they represent and as such, the obtained results are entirely representative of the material. This means that the properties shown on the material test certificate are going to be representative of the component the material is making (this is not the case for castings).

Therefore the figures in Table 1 can be used for design.

The cast version of this alloy (Def Stan 02-824 Part 1) calls for small test bars that are cast separate to the castings they represent. As the test piece for cast material is usually smaller than the component it is not representative and actual properties in the castings would routinely be lower. Because of this, Def Stan 02-824 suggests, for design purposes, a 0.2% proof stress of 240MPa (35Ksi) should be used, which is significantly lower than wrought CAL CNC-1.

Typical testing standards for wrought CNC include:

Tensile Test Standard: BS EN 2002-1
Impact Test Standard: BS 131 Part 1
Hardness Test Standard: BS EN ISO 6506-1

CAL Wrought CNC-1 | High strength wrought Copper-Nickel-Chrome Alloy

CuNi30Cr1MnFeSiZrTi

Table 1 - Physical Properties (approx)

Properties	**Metric**	**Imperial**
Melting point	1,180-1,230°C	2,156-2,246°F
Density	8,800 kg/m³	0.318 lbs/in³
Specific Heat	0.411 J/(g.K)	0.0982 Btu/ (lb.°F)
Thermal Conductivity @ 20°C	23 W/(m.K)	13.3 Btu/(Hour. Ft.°F)
Electrical Conductivity %IACS at 20°C	5	5
Electrical Resistivity at 20°C	0.35 µ.Ω.m	13.8 µ.Ω.in
Magnetic Permeability (µr)	< 1.01	< 1.01
Coefficient of linear expansion (20-250°C)	18.0 x 10^{-6}/°C	10.0 x 10^{-6}/°F
Young's Modulus, Modulus of Elasticity	143,000 N/mm²	20,740 ksi
Modulus of Rigidity	54,000 N/mm²	7,832 ksi
Shear Strength	240-260 N/mm²	34.8 ksi
Poisson's Ratio	0.3	0.3

Additional information can be provided upon request.

BACKGROUND

Our expertise allows us to cast high quality ingots suitable for forging, using advanced melting, alloying and casting techniques. Additionally, our deep metallurgical understanding of forging and other hot working activities, allows us to create a range of high quality wrought products including forgings (rings, discs, blocks, shafts, closed die forgings) and bars (round, square, hexagonal, flats).

Copper Alloys specialise in the production of finish machined turnkey complex components. With modern CNC machining techniques it is possible to upgrade most castings to machined forgings.

Wrought CNC is available as:

CAL CNC-1: The ductile material applicable to all product forms and sizes

Related Specifications:

Def Stan 02-824 Part 1 (Cast CuNiCr)
Def Stan 02-886 Part 1 (Wrought CuNiCr)

COMPOSITION

Traceability from source to customer is guaranteed.

Table 2 - Composition Requirements Weight %

Alloying Elements						
Cu	Ni	Cr	Fe	Mn	Zr	Ti
Remainder	29.0-32.0	1.6-2.0	0.5-1.0	0.5-1.0	0.05-0.15	0.03-0.15
Impurity Elements - low levels consistent with Defence Standards (all figures are maximum) Permitted Total of these Impurities 0.50% maximum by weight						
Pb	P	Bi	Sn	C	Total Impurities	
0.05	0.05	0.02	0.10	0.02	0.50	

FORMS AVAILABLE

Copper Alloys Ltd can provide the largest ingots and heaviest-section forged products available anywhere due to industry-leading process technology that ensures a large total forging reduction and a uniform fine-grain wrought structure in the finished product.

Our capacity continues to evolve and widen as we service ever increasing customer demands, the current range includes:

- Bars (square/flat/round) from 10mm to 500mm (0.375”-20”) in section
- Forgings (to 25,000Kg): Blocks/Rings to 2400mm (8ft) outer ø/Shafts to 7000mm (23ft) long/Discs to 1270mm (50”) ø
- Proof machined or finished components built to print

APPLICATIONS

Marine applications requiring high strength coupled with excellent corrosion resistance and high fracture toughness / resistance to shock. The ability of the material to resist bio-fouling (lack of marine growth) is another important feature of this material.

It can also be used in marine applications for valve bodies, valve internals (seats, balls, stems seal-rings), actuators, pump bodies and pump internals.

Widely used on naval platforms for weapon handling systems, salt water intake valves and sumps, pump parts, sonar equipment, shafts, mechanical seals, flanges, fasteners and many other applications where high resistance to marine corrosion, in particular resistance to pitting, combined with low magnetic permeability and non-sparking properties are required.

It is used in the oil and gas industry for riser bolting, subsea manifolds, heat exchangers, caissons and splash zone applications, as well as for down-hole equipment and stab plate connectors, actuator components, shafts for pumps & valves, valve stems and subsea clamps.

INSPECTION AND CERTIFICATION

All material is subjected to chemical analysis and mechanical testing to ensure compliance with Tables 1 & 2.

Different levels of testing and inspection are automatically triggered by ordering according to Table 5 below, derived from the generic material specification Def Stan 02- 835 Part 2. Additional testing can be agreed e.g. Dye Penetrant Inspection of Grade 1 rods and bars, or alternative NDE standards.

Certification is provided as standard in both wet-signed and electronic form (soft-copy) in accordance with EN 10204 type 3.1. Certification to 3.2 can also be provided upon request.

Table 3 - Testing and Qualification Criteria

Product form	**Bars**		**Forgings**
Grade / Class[A]	Grade 1[A]	Class 1[A]	Class 2[A]
Chemical Analysis (melt)	Every cast	Every cast	Every cast
Mechanical Testing[B]	Every cast for each size Integral sample[B]	Each and every forging Integral sample[B]	One forging every cast/ size Integral sample[B]
Ultrasonic Inspection	100% Def Stan 02-729 Part 5	100% Def Stan 02-729 Part 5	100% Def Stan 02-729 Part 5
Dye Penetrant Inspection	Available on request	Available on request	100% Def Stan 02-729 Part 4
Visual Inspection	100%	100%	100%
Eddy Current[C]	100% Def Stan 02-729 Part 3[C]	100% Def Stan 02-729 Part 3[C]	100% Def Stan 02-729 Part 3[C]

A: *Material is offered to Grade 1 and Classes 1 & 2 only which is the higher level of mechanical testing and NDE compared with Grade 2 and Class 3.*

B: *For all Grades and Classes, test samples are integral to the item and the property results are therefore fully representative of the certified material.*

C: *Eddy current testing has been historically used for evaluating the presence of dangerous linear oxide defects at / near the surface, which cannot be detected using radiography, and castings cannot be ultrasonically inspected due to poor grain size and grain structure. Our wrought CNC-1, due to a very fine grain structure and resulting low attenuation, can be very effectively ultrasonically inspected. Ultrasonic testing combined with dye penetrant inspection supercede Eddy Current Testing in accurately identifying material defects before machining. When industry has fully embraced this improvement, this table will be updated accordingly.*

MECHANICAL PROPERTIES CAL CNC-1

High Strength Copper-Nickel-Chrome Alloy CAL CNC-1

CuNi30Cr1MnFeSiZrTi

Fully conforms to Def Stan 02-886

Table 4 - Guaranteed Minimum Mechanical Properties

Product	**Bars - round, square, flats, hexagon, shapes**		**Forgings**	**Cast CNC Def Stan 02-824 Part 1 for reference**
	Material section-size (minor dimension)			
Property	Up to and including 150mm (6”)	Over 150mm (6”)	All sizes	
	CNC-1	CNC-1	CNC-1	
Ultimate Tensile Strength Rm MPa	580 (84Ksi)	550 (80Ksi)	550 (80Ksi)	480 (70Ksi)
0.2% Proof Stress Rp0.2 MPa	390 (57Ksi)	350 (51Ksi)	350 (51Ksi)	300 (44Ksi) 240 (35Ksi) for design
% Elongation after Fracture 5.65 √ So	20	20	20	18
Izod Impact J	110 (81ft lbf)	110 (81ft lbf)	110 (81ft lbf)	Typical 45-60 (33-44ft lbf)
Hardness Brinell HB 10/3000**	*160-200	*160-200	*160-200	*Typical 170-200

** For reference only - does not form part of the acceptance criteria unless agreed.*

MANUFACTURE

This outstanding material (Copper-Nickel-Chrome; CNC) was developed by the British MoD to replace Nickel Aluminium Bronze (NAB) in sea water systems in submarines, due to corrosion issues with NAB - in particular selective phase corrosion (SPC). The depth of attack in NAB is typically 1.1mm/year (0.043”/year), but has been observed at 1.4mm/year (0.055”/year).

CNC is reported to have the ability to last the lifetime of the platform and observed 10 years service performance showing excellent results with negligible corrosion and fit for a second commission. CNC does not contain continuous/semi-continuous anodic phases and as such, is immune to SPC and has a very low general corrosion rate of <0.02mm/year (<0.0008”/year).

The advanced metallurgical expertise at Copper Alloys Ltd which enhance melting, alloying and casting techniques, combined with the development of process technology in hot working materials, have enabled the production of two forged versions of the alloy, which have expanded the envelope of what is possible for marine alloys.

If you are using NAB in critical sea water systems, where resistance to corrosion and high shock resistance is required, we strongly recommend you to consider using wrought CNC. This alloy is designed to last the lifetime of a vessel, and in effect with CNC-1, marine engineers can fit and forget.

APPLICATIONS

This combination of properties is unique and consequently is unavailable elsewhere in a copper-based alloy.

Wrought CNC is specifically designed for applications where a combination of high shock resistance (resistance to crack propagation under dynamic loading) combined with high resistance to sea water corrosion is required. In particular, it offers benefits for critical components in equipment used in military submarines and surface vessels, where longevity and functionality are crucial over the life of the platform.

Current components being manufactured in Nickel Aluminium Bronze can be replaced by CAL Wrought CNC-1 generally without the need to change geometry, however this will lead to an increase in component weight of around 15% due to the increase in density. If however, full use is made of the following benefits, a decrease in component weight can be designed in, with obvious benefits including reduced inertia under shock conditions:

- Increased 0.2% proof stress over NAB - twice as strong.
- Massively increased resistance to shock of NAB - five-times greater.
- Much higher sea water corrosion resistance. In particular very low crevice corrosion and lack of selective phase corrosion i.e. reduction in in-service corrosion allowance - 10-times greater.
- Like conventional cupro-nickel alloys, CuNiCr can suffer from galling. When excellent anti-galling characteristics are required, extreme-strength cupro-nickel CAL T-1000 CuAl14Al2 is recommended.
- Typical applications include sea water retaining covers, clamps, flanges, valve bodies and internal components, seal-rings, actuators heat exchangers.

CORROSION DATA

Wrought CuNiCr is specifically designed for applications where a combination of high shock resistance (resistance to crack propagation under dynamic loading) combined with high resistance to sea water corrosion is required. In particular, it offers benefits for critical components in equipment used in military submarines and fighting ships, where longevity and functionality are crucial over the life of the platform. The structure of the alloy is free from vulnerable phases and as such is immune to selective phase corrosion (SPC), unlike Nickel Aluminium Bronze. Corrosion is only slight and general (on the metal surface) with no sub-surface attack, making the material fit for wetted sealing-faces. Being a copper based alloy, the materials resistance to marine bio-fouling is high and similar to conventional copper-nickel alloys, such as 90/10 and 70/30 Cupro Nickel. Surfaces therefore remain 'clean', avoiding accelerated corrosion and reduced functionality associated with marine growth.

The electrochemical potential of wrought CuNiCr is similar and compatible with the other copper alloys used in sea water systems, for example 90/10 and 70/30 CuNi alloys and Nickel Aluminium Bronze and are interchangeable within systems.

Table 5 - Overview of benefits of CAL Wrought CNC-1 compared with Nickel Aluminium Bronze (NAB) and cast CNC

CAL Wrought CNC-1	**Nickel Aluminium Bronze**	**Cast CNC**
Fine, homogeneous, equi-axed grain structure *free from phases that can be preferentially attacked in sea water. Hot forging densifies the structure, eliminating micro cavities. *ASTM E112 grain size 5-6 typically observed	Complex multi-phase microstructure with risk of semi-continuous anodic phases.	Grain structure free from phases that can be preferentially attacked in sea water. Coarse cast structure with coring (alloying element segregation across grains), with inter-granular and inter-dendritic micro cavities and non-uniform grain size between sections of differing thickness.
Ability to be easily penetrated using conventional ultrasonic pulse echo techniques, permitting detailed volumetric inspection to (for example) Def Stan 02-729 Part 5, rather than expensive radiography.	Wrought version (Def Stan 02-833) can be ultrasonically inspected whereas cast version (Def Stan 02-747) in practice, needs to be radiographed which is more expensive.	Coarse cast grain structure scatters and absorbs ultrasound resulting in very high attenuation. Can only be inspected volumetrically using radiography, which is relatively expensive compared with ultrasonic inspection and does not detect metal oxide films.
In-service wall thickness measurements using ultrasonic thickness gauge can be carried out to check corrosion rate in-situ, without the need to remove to check corrosion damage (does not suffer SPC).	Wrought version (Def Stan 02-833) can be checked using ultrasonic thickness gauge whereas cast version (Def Stan 02-747) cannot. Selective phase corrosion, in particular in hard to reach crevices, limits its use.	Corrosion rate cannot be monitored in-situ using ultrasonic thickness gauge techniques. Component needs physically removing to inspect corrosion damage.
No selective phase corrosion (SPC). High general corrosion resistance in sea water <0.02mm/year (<0.0008”/year).	Selective phase corrosion 0.5-1.0mm / 0.002 0.04”. General corrosion resistance in sea water ~ 0.025-0.05mm/year (0.001-0.002”/year).	No selective phase corrosion (SPC). High general corrosion resistance in sea water <0.02mm/year (<0.0008”/ year).
Homogenous refined wrought structure induces a high combination of mechanical properties IN THE ACTUAL PRODUCT, far higher than the Def-Stan 02-824 part 1 (see mechanical property section).	Wrought version (Def Stan 02-833) has integral test pieces however cast version (Def Stan 02-747) does not and actual test results obtained from castings often fall short of specification minimum values which are for separately cast test bars.	Coarse cast grain structure differing from thin to thick sections of castings may result in actual mechanical properties in the product significantly less than the specification minimum requirements, which are determined on a separately cast test bar.
Very high Impact Strength ~ 100J higher than NAB and over twice that of cast CNC: CAL CNC-1 Guaranteed ≥ 110J / 81 ft l bf (typical 120-150J / 89- 111 ft lbf). Determined on samples taken from the actual product - highly representative.	Low impact strength: Cast Def Stan 02-747 Not specified, typically ~ 17-25J / 13-18ft lbf on separately cast test bar. Wrought Def Stan 02-833 Specified as 23-27J / 17-20ft lbf minimum (size dependant). Typically ~ 30-40J/ 22-30 ft lbf - integral test sample for wrought grades.	Moderate impact strength: No specified requirement for cast material. Typically ~ 45-60J / 33-44ft lbf on a separately cast test bar NOT from cast product.
High 0.2% proof stress about twice that of NAB and cast CNC: CAL CNC-1 Guaranteed ≥ 350- 390MPa / 51-57Ksi (depending on section size) Typically 380- 480MPa / 55-70 Ksi. Determined on samples taken from the actual product - highly representative.	Low 0.2% proof stress: Castings Def Stan 02-747 specified as > 250MPa / 36 Ksi on separately cast test bar (castings themselves would typically be lower). Wrought Def Stan 02-833 specified as 245-325MPa / 36-47 Ksi (size dependent). Typically 280-380MPa / 41-55 Ksi - integral test sample for wrought grades.	Low 0.2% proof stress: Specified as 300MPa / 44 Ksi minimum but is determined on a separately cast test bar unrepresentative of the actual properties in the castings. Specification guide-line is to design on a minimum expected proof stress in the castings of 240MPa / 35Ksi.
Issue of linear oxide films from reactive alloying elements (Cr, Ti, Zr): Wrought CNC-1 is free from detrimental linear oxide defects. The small grain size and resulting low attenuation to ultrasound permits detailed volumetric inspection and this, combined with dye penetrant inspection, can confirm material is within the defect acceptance criteria as required by Def Stan 02-729 parts 5 & 4 respectively.	Issue of linear oxide films from reactive alloying elements (Cr, Ti, Zr): Non-issue.	Issue of linear oxide films from reactive alloying elements (Cr, Ti, Zr): Cannot be detected using radiography making surface inspection using eddy current techniques required, which only determines integrity of material at or near surface.

Table 6 - Comparison of Corrosion Resistance Between Marine Alloys

	CAL Elite Marine Alloys			**Other commonly used Marine-Alloys (also offered by CAL)**								
Material	Extreme Strength Cupro Nickel	High Strength Copper-Nickel-Manganese-Aluminium Alloy	Wrought Copper-Nickel-Chrome (CNC) Alloy	Wrought Nickel Aluminium Bronze (NAB)	Cast Nickel Aluminium Bronze (NAB)	70/30 Cupro Nickel	90/10 Cupro Nickel	Naval Brass	Nickel-Copper Alloy	Nickel-Copper-Aluminium-Titanium Alloy	Stainless Steel	Stainless Steel
Base composition	CuNi14Al2	CuNi15Mn4-Al1Fe	CuNi30Cr1 MnFeSiZrTi	CuAl9Ni5Fe4	CuAl9Ni5Fe4	CuNi30Mn1Fe	CuNi10Fe1Mn	CuZn37Sn1	NiCu30 Fe2Mn1	NiCu30Al-3Fe1MnTi	FeCr18Ni9	FeCr18Ni-12Mo2
Specification property	CAL T-1000 (DIN 2.1504)	CAL T-850	CAL CNC-1	NES 833 DGS 1043 CW307G	NES 747 CC333G	NES 780 CN107 C71500 CW354H	NES 779 CN102 C70600 CW352H	CZ112 CW712R C46400	NA13 / UNS N04400	NA18 / UNS N05500	304 Stainless	316 Stainless
General corrosion rate per year	0.02mm / 0.0008"	0.025mm / 0.001"	0.02mm / 0.0008"	0.025-0.05mm / 0.001-0.002"	0.07mm / 0.002"	0.03mm / 0.001"	0.03mm / 0.001"	0.05mm / 0.002" (4 x at 60°C)	0.03mm / 0.001"	0.03mm / 0.001"	.025mm / 0.001"	0.07mm / 0.003"
Crevice corrosion rate per year	<0.02mm / 0.0008"	<0.025mm / 0.001"	<0.02mm / 0.0008"	0.5mm / 0.02"	0.5mm / 0.02"	0.025-0.13mm / 0.001-0.005"	0.025-0.13mm / 0.001-0.005"	0.15mm / 0.006"	0.5mm / 0.020"	0.05mm / 0.002"	0.25mm / 0.010"	0.5mm / 0.02"
Selective phase corrosion per year	None	None	None	0.5-1.0mm / 0.02-0.04"	1.1mm (0.04") typical 1.4mm (0.055") observed	None	None	0.15mm / 0.006"	None	None	None	1.1mm (0.04") typical 1.4mm (0.055") observed
Impingement resistance limit m/second	3.7m/s (12ft/sec.)	3.7m/s (12ft/sec.)	6-8m/s (20-26ft/sec.)	4.3m/s (14ft/sec.)	4.3m/s (14ft/sec.)	4.6m/s (15ft/sec.)	3.7m/s (12ft/sec.)	3.05m/s (10ft/sec.)	>9.1m/s (>30ft/sec.)	>9.1m/s (>30ft/sec.)	>9.1m/s (>30ft/ sec.)	4.3m/s (14ft/sec.)
Corrosion potential in seawater ^{V}sce	-0.18	-0.19	-0.18	-0.19	-0.19	-0.18	-0.20	-0.24	-0.12	-0.12	-0.08	-0.19
Marine bio-fouling resistance	Highly resistant	Highly resistant	Highly resistant	Partially resistant	Partially resistant	Resistant	Highly resistant	Partially resistant	Not resistant	Not resistant	Not resistant	Not resistant

The manufacturer reserves the right to modify alloy composition, properties and processing.

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