# Material Selection for Marine Bearings: The Engineering Conflict Between Cavitation Resistance and Self-Lubrication

## An Engineering Analysis of CuAl10Fe5Ni5, CuSn12, CuSn10Pb10, and RG5 for Extreme Fluid Environments

Selecting materials for self-lubricating bearings and fluid transmission components in marine applications presents a fundamental metallurgical challenge: How do you specify an alloy that withstands aggressive seawater cavitation while also providing reliable dry-running lubrication?
For material engineers, this is not simply a trade-off—it is a direct physical contradiction. The microstructure required to resist the violent forces of cavitation is inherently opposed to the one needed for effective self-lubrication.
This article provides a technical breakdown of four standard EN 1982 bronze alloys. Rather than declaring a single "best" option, we will analyze the specific engineering conflicts, operational risks, and manufacturing realities associated with each, enabling you to make a structurally sound decision based on your system's design priorities.

## 1. The Core Conflict: Cavitation Resistance vs. Friction Management

Before evaluating specific alloys, it is essential to understand the extreme boundary conditions present in applications such as pump housings, high-load bearings, and worm gears.
★ **The Physics of Cavitation:** When localized fluid pressure drops below vapor pressure, vapor bubbles form and collapse. These implosions generate microscopic shockwaves that can exceed **1,000 MPa**. To withstand this repeated stress, a material must possess high yield strength, superior hardness, and a dense, non-porous microstructure.
★ **The Physics of Self-Lubrication:** Effective dry-running capability relies on soft phases—typically lead (Pb)—dispersed throughout the alloy matrix. Under friction, these particles smear across the surface, creating a sacrificial boundary layer that prevents metal-to-metal contact and galling.
These two sets of requirements are mutually exclusive. A hard, dense structure resists cavitation but lacks lubricity. A soft, lead-rich structure provides lubrication but is vulnerable to cavitation erosion.
The following matrix cross-references the critical mechanical properties of four common marine bronzes against these opposing demands.

### Comparative Engineering Matrix: Marine Bearing Alloys

| Alloy Designation (EN 1982) | 0.2% Yield Strength | Hardness (HB) | Free-Lubricating Phase (Pb%) | Machinability Index | Cavitation Resistance | Dry-Running Risk |
|---|---|---|---|---|---|---|
| CuAl10Fe5Ni5 (Nickel Aluminum Bronze) | 280 MPa | 150 | < 0.03% (None) | 50 (Difficult) | Exceptional | Severe Galling Risk – Requires external lubrication. |
| CuSn12 (High Tin Bronze) | 150 MPa | 90 | < 0.7% (Minimal) | 20 (Extreme Tool Wear) | Moderate / Good | High Total Cost of Ownership – Driven by machining difficulty. |
| CuSn10Pb10 (High-Leaded Tin Bronze) | 110 MPa | 70 | 8-11% (Excellent) | 80 (Easy) | Catastrophic Failure | Lead phase is rapidly eroded by cavitation. |
| CuSn5Zn5Pb5 (RG5 / Red Brass) | 110 MPa | 65 | 4-6% (Good) | 84 (Excellent) | Poor | High Risk – Susceptible to dezincification and cavitation damage. |

Note: Mechanical properties are based on continuous or centrifugal cast nominal averages. Actual in-service performance will vary non-linearly depending on applied Pressure x Velocity (PV) values.

## 2. Material-by-Material Risk Analysis

When designing for seawater exposure with cavitation risk, selecting the wrong alloy can lead to rapid, catastrophic failure. Here is a detailed look at the operational profile for each material.

## Option A: CuAl10Fe5Ni5 (Nickel Aluminum Bronze) – The Cavitation Specialist

★ **The Engineering Premise:** The combination of aluminum, nickel, and iron forms a complex, high-strength solid solution. In seawater, it immediately develops a tough, self-repairing oxide passivation layer. With a high yield strength of 280 MPa, this alloy is engineered to deflect the energy of collapsing cavitation bubbles effectively.
★ **The Operational Risk:** This alloy is fundamentally incapable of self-lubrication. It contains no free lead. The very oxide layer that provides its excellent seawater corrosion resistance becomes an abrasive surface under dry or boundary friction conditions, leading to rapid galling and seizure.
★ **The Design Question:** If you specify CuAl10Fe5Ni5 for a bearing application, can your system guarantee a continuous hydrodynamic lubricating film? If the answer is no, and you require any degree of dry-running or maintenance-free operation, this material presents a significant seizure risk.

### Chemical Composition

| Elements | Cu | Al | Ni | Fe | Mn | Zn | Si | Sn | Cr | Mg | Pb | Bi |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EN 1982 | 76-83 | 8.5-10.5 | 4-6 | 4-5.5 | 3.0 max | 0.5 max | 0.1 max | 0.1 max | 0.05 max | 0.05 max | 0.03 max | 0.01 max |
| Average Nominal | 78 | 9 | 5 | 5 | 2.56 | 0.30 | 0.1 | 0.1 | 0.05 | 0.05 | 0.02 | 0.01 |

### Related Specifications

| DIN EN 1982 | BS 1400 | ASTM B505 | ASTM B271 |
|---|---|---|---|
| CC333G | AB2 | C95500 | C95500 |

## Option B: CuSn10Pb10 (High-Leaded Tin Bronze) – The Lubrication Expert

★ **The Engineering Premise:** With approximately 10% insoluble lead distributed throughout its matrix, this alloy offers exceptional boundary lubrication. It is an ideal candidate for heavily loaded bearings in applications where an external lubricant cannot be supplied.
★ **The Operational Risk:** Cavitation will destroy this material. The intense pressure waves generated by bubble collapse act like micro-explosions, forcibly ejecting the soft lead particles from the copper-tin matrix in a process known as "washout." The resulting surface pitting creates a porous, sponge-like structure that dramatically accelerates crevice corrosion in a seawater environment.
★ **The Design Question:** Can your system design (e.g., pump housing, bearing location) guarantee a completely cavitation-free zone? If not, CuSn10Pb10 is likely to fail prematurely. Furthermore, does your target market or regulatory environment restrict the use of lead (Pb) under directives like RoHS or REACH?

### Chemical Composition

| Elements | Cu | Sn | Pb | Ni | Zn | Sb | Fe | Mn | S | P | Al | Si |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EN 1982 | 78-82 | 9-11 | 8-11 | 2 max | 2 max | 0.5 max | 0.25 max | 0.2 max | 0.1 max | 0.1 max | 0.01 max | 0.01 max |
| Average Nominal | 80 | 10 | 9 | 0.5 | 0.2 | 0.1 | 0.1 | 0.05 | 0.04 | 0.005 | 0.004 | 0.001 |

### Related Specifications

| DIN EN 1982 | BS 1400 | ASTM B505 | ASTM B271 |
|---|---|---|---|
| CC495K | LB2 | C93700 | C93700 |

## Option C: CuSn12 (High Tin Bronze) – The High-Cost Compromise

★ **The Engineering Premise:** CuSn12 attempts to balance the two extremes. Its high tin content (11-13%) creates a dense, tough matrix with a yield strength of 150 MPa, providing good resistance to moderate cavitation and wear. It is often specified for highly stressed components like worm wheels.
★ **The Operational Risk:** The primary drawback is manufacturability. With a machinability rating of just 20, CuSn12 is notoriously difficult and expensive to machine. Tool wear is extreme, and cutting speeds must be significantly reduced, driving up production time and cost.
★ **The Design Question:** While CuSn12 offers a reasonable compromise in terms of performance, can your budget absorb the significantly higher per-part machining costs? The savings in material selection may be lost many times over in the machine shop.

### Chemical Composition

| Elements | Cu | Sn | Ni | Pb | P | Zn | Mn | Fe | Sb | S | Al | Si |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EN 1982 | 85.0-88.5 | 11.0-13.0 | 2.0 max | 0.7 max | 0.6 max | 0.5 max | 0.2 max | 0.2 max | 0.15 max | 0.05 max | 0.01 max | 0.01 max |
| Average Nominal | 86 | 11 | 1.5 | 0.5 | 0.4 | 0.25 | 0.2 | 0.1 | 0.02 | 0.01 | 0.01 | 0.01 |

### Related Specifications

| EN1982 | ASTM B 427 |
|---|---|
| CC483K | C90800 |

## Option D: CuSn5Zn5Pb5 (RG5 / Red Brass) – The Outdated Generalist

★ **The Engineering Premise:** Historically, RG5 was a common choice for low-pressure steam fittings and water plumbing due to its excellent thermal conductivity (72.0 W/m·K) and ease of casting and machining.
★ **The Operational Risk:** In a modern, high-stress marine environment with seawater and cavitation, RG5 is inadequate. The 4-6% zinc content presents a significant risk of dezincification, where zinc is selectively leached from the alloy, leaving behind a weak, porous copper structure. Its low yield strength also offers poor resistance to cavitation.
★ **The Design Question:** Industry data shows RG5 is being phased out for dynamic marine components in favor of more robust alloys like CuSn7Zn4Pb7-C. Unless your application is strictly limited to static, low-pressure, non-cavitating fluid housings, RG5 is not a recommended choice.

### Chemical Composition

| Elements | Cu | Zn | Sn | Pb | Ni | Fe | Sb | P | S | Al | Si |
|---|---|---|---|---|---|---|---|---|---|---|---|
| EN 1982 | 83.0-87.0 | 4-6 | 4-6 | 4-6 | 2.0 max | 0.3 max | 0.25 max | 0.1 max | 0.1 max | 0.01 max | 0.01 max |
| Average Nominal | 83 | 5 | 5 | 5 | 1.62 | 0.1 | 0.1 | 0.1 | 0.05 | 0.01 | 0.01 |

### Related Specifications

| DIN EN 1982 | BS 1400 | ASTM B271 | ASTM B505 |
|---|---|---|---|
| CC491K | LG2 | C83600 | C83600 |

## 3. The Engineering Decision: Defining Your Next Steps

Selecting a bronze alloy for a self-lubricating component in a cavitating environment is not about finding a perfect material—it does not exist. It is about choosing which inherent limitation you are best prepared to mitigate through system design.

**Based on the metallurgical realities outlined above, your design team must make a binary decision before finalizing any drawings:**

1. **If you Prioritize Cavitation Survival (The CuAl10Fe5Ni5 Path):**
You must commit to a mechanical design that ensures continuous lubrication, either through a forced hydrodynamic system or by using the surrounding seawater as a lubricant. You must also consider surface hardening for the mating shaft. This path means completely abandoning any requirement for true "dry-running" capability.
2. **If you Prioritize Friction & Wear (The CuSn12 Path):**
You accept a moderate level of cavitation resistance. To make this viable, your budget and timeline must account for the significantly higher machining costs and extended lead times associated with processing high-tin bronze.

**To move from theoretical data to a reliable lifespan calculation for your application, you must first verify these critical boundary conditions:**

★ What is the absolute peak **PV (Pressure x Velocity)** value the component will experience?
★ Is **boundary lubrication** (even from seawater alone) guaranteed during start-up, shut-down, or other periods of operation?
★ Are you subject to any **lead-free (Pb-free) environmental directives** in your target markets?

Accurate material specification requires confronting these extreme variables. Assess your system's exact tolerances for friction damage versus cavitation erosion before locking in your bill of materials.