


Havar®, Elgiloy®, and Phynox® - A Comparative Technical Review of High-Performance Cobalt-Chromium Alloys

Abstract

Havar®, Elgiloy®, and Phynox® are three high-performance cobalt-chromium-nickel alloys widely specified in precision engineering, medical devices, scientific instrumentation, and nuclear applications. Despite sharing a common alloy family, they exhibit distinct compositional, mechanical, and processing characteristics that make each better suited to specific application requirements. This paper presents a systematic technical comparison of the three alloys across composition, mechanical properties, physical properties, oxidation behaviour, corrosion resistance, biocompatibility, fabrication behaviour, and application suitability, integrating published scientific data and primary research to provide a structured basis for alloy selection in demanding engineering contexts.

1. Introduction

The cobalt-chromium alloy family occupies a unique position in advanced materials engineering, offering combinations of strength, corrosion resistance, non-magnetic behaviour, and biocompatibility that are difficult to replicate with conventional stainless steels or nickel-based superalloys. Within this family, Havar®, Elgiloy®, and Phynox® have each established strong application track records — Havar® in nuclear physics and medical isotope production, Elgiloy® in precision springs and medical implants, and Phynox® in watch components, surgical instruments, and corrosion-critical applications.

All three alloys are precipitation-hardenable, non-magnetic, and available in thin foil, disc and coil form, yet their compositional differences produce meaningfully different property profiles. Understanding these distinctions is essential for engineers selecting materials for applications where performance margins are narrow and failure is not acceptable. The growing use of cobalt-chromium alloys in medical isotope production, implantable devices, and ultra-high vacuum systems has generated a substantial body of scientific literature characterising these materials under real service conditions, and this review draws on that body of work to provide an evidence-based comparison.

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2. Compositional Overview

All three alloys are based on the Co-Cr-Ni-Fe system, with additions of Mo, W, and Mn to modify strength, corrosion resistance, and processing behaviour. Table 1 summarises their nominal compositions.

ELEMENT (WT%)	HAVAR®	ELGILOY®	PHYNOX®
COBALT (CO)	42.0%	40.0%	40.0%
CHROMIUM (CR)	19.5%	20.0%	20.0%
NICKEL (NI)	12.7%	15.0%	15.0%
IRON (FE)	Balance	Balance	Balance
MOLYBDENUM (MO)	2.2%	7.0%	7.0%
TUNGSTEN (W)	2.7%	—	—
MANGANESE (MN)	1.6%	2.0%	2.0%
CARBON (C)	0.2%	0.15% max	0.15% max
BERYLLIUM (BE)	—	0.04%	—

Table 1 — Nominal Composition (wt%)

The most significant compositional differences are the higher molybdenum content in Elgiloy® and Phynox® (7.0% vs 2.2% in Havar®), the presence of tungsten in Havar® (2.7%), and the inclusion of beryllium in Elgiloy® (0.04%). Phynox® is essentially a beryllium-free variant of Elgiloy®, developed to address biocompatibility and occupational health concerns associated with beryllium processing. The higher molybdenum content of Elgiloy® and Phynox® confers superior resistance to pitting and crevice corrosion in chloride-rich environments, while Havar®'s tungsten addition contributes to solid-solution strengthening and elevated-temperature stability, consistent with the behaviour of tungsten-bearing cobalt superalloys documented by Donachie and Donachie [20].

3. Mechanical Properties

All three alloys are supplied in annealed, cold-rolled, and age-hardened conditions, with mechanical properties varying significantly between conditions. Table 2 summarises typical mechanical properties in the cold-rolled and age-hardened (peak) condition.

PROPERTY	HAVAR®	ELGILOY®	PHYNOX®
ULTIMATE TENSILE STRENGTH	2,275 MPa (330,000 PSI)	2,070 MPa (300,000 PSI)	2,000 MPa (290,000 PSI)
0.2% PROOF STRESS	2,069 MPa (300,000 PSI)	1,900 MPa (275,000 PSI)	1,850 MPa (268,000 PSI)
HARDNESS	RC 60	RC 58	RC 56–58
ELASTIC MODULUS	203 GPa (29.5 × 10^6 PSI)	195 GPa (28.3 × 10^6 PSI)	195 GPa (28.3 × 10^6 PSI)
ELONGATION (ANNEALED)	40%	35%	35%

Table 2 — Typical Mechanical Properties (Cold-Rolled, Age-Hardened)

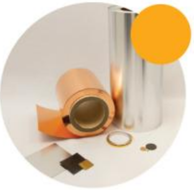
Havar® achieves the highest peak tensile strength of the three alloys, a consequence of combined solid-solution strengthening from tungsten and the precipitation hardening response developed through cold work and age hardening. Elgiloy® and Phynox® exhibit closely comparable mechanical properties, with Elgiloy® holding a marginal advantage attributable to its beryllium addition. In the annealed condition, all three alloys offer sufficient ductility for complex forming operations, though Havar®'s higher carbon content contributes to a more pronounced work-hardening rate during cold rolling [4].

3.1 Fatigue Performance

All three alloys exhibit excellent fatigue resistance under cyclic loading. Jiang et al. [5] characterised the fatigue crack growth behaviour of cobalt-chromium alloys for medical applications, demonstrating that the combination of high yield strength and low crack propagation rate in these alloys produces fatigue endurance limits that significantly exceed those of austenitic stainless steels at comparable stress amplitudes. Marrey et al. [6] developed a comprehensive fatigue life prediction framework specifically for cobalt-chromium stents, confirming that Elgiloy®-class alloys sustain more than 10^8 cycles at physiologically relevant stress amplitudes without crack initiation when processed to tight microstructural tolerances. Havar®'s higher UTS translates to a proportionally higher fatigue endurance limit, making it the preferred material in spring and diaphragm applications subject to high-cycle loading.

3.2 Elevated Temperature Behaviour

Havar® retains approximately 75% of its room-temperature strength at 510 °C (950 °F) and offers dimensional stability up to 400 °C, making it the preferred choice where elevated-temperature performance is required. Elgiloy® and Phynox® are generally recommended for service up to approximately 315 °C (600 °F), beyond which property retention diminishes more rapidly. This difference is attributable to Havar®'s tungsten content, which stabilises the cobalt matrix against thermally activated dislocation recovery and precipitate coarsening at intermediate temperatures, consistent with the solid solution strengthening mechanisms in cobalt superalloys documented by Donachie and Donachie [20].



4. Physical Properties

PROPERTY	*HAVAR®*	*ELGILOY®*	*PHYNOX®*
DENSITY	*8.30 G/CM^3*	*8.30 G/CM^3*	*8.30 G/CM^3*
MELTING POINT	*~1,480 °C*	*~1,480 °C*	*~1,480 °C*
ELECTRICAL RESISTIVITY	*92 μΩ·CM*	*99 μΩ·CM*	*99 μΩ·CM*
THERMAL CONDUCTIVITY	*13.0 W/M·K*	*12.0 W/M·K*	*12.0 W/M·K*
THERMAL EXPANSION COEFFICIENT	*12.5 × 10^{-6}/°C*	*12.8 × 10^{-6}/°C*	*12.8 × 10^{-6}/°C*
MAGNETIC PERMEABILITY (μR)	*≈ 1*	*≈ 1*	*≈ 1*

Table 3 — Physical Properties

The three alloys are physically very similar, sharing the same density and melting point range. All are non-magnetic ($\mu r \approx 1$), which is a defining characteristic of the cobalt-chromium alloy family and a key driver of their selection in MRI-compatible and magnetically sensitive applications. The stopping power of Havar® for energetic protons and light ions — a critical parameter in cyclotron target design — has been characterised by Seltzer and Berger [12], whose evaluated stopping power data for cobalt-chromium alloy compositions provides the physical basis for Havar®'s use as a thin beam window material. The slightly higher electrical resistivity of Elgiloy® and Phynox® is attributable to their higher molybdenum content.

5. Corrosion Resistance

All three alloys offer excellent general corrosion resistance by virtue of their chromium content, which promotes the formation of a stable, self-repairing passive oxide layer. However, their performance in specific corrosive environments differs meaningfully.

Elgiloy® and Phynox® demonstrate superior resistance to pitting and crevice corrosion in chloride-containing environments — including physiological saline and seawater — owing to their higher molybdenum content (7.0% vs 2.2% in Havar®). Pound [8] characterised the electrochemical behaviour of cobalt-chromium alloys in simulated physiological solution using potentiodynamic polarisation, demonstrating that increasing molybdenum content shifts the pitting potential to significantly more noble values and reduces the passive current density, confirming the role of molybdenum in stabilising the passive film against chloride-induced breakdown. This makes Elgiloy® and Phynox® the preferred choice for long-term implantable devices and marine applications.

Havar® offers excellent corrosion resistance for industrial, scientific, and nuclear applications, and its performance in non-chloride environments is broadly comparable to the other two alloys. Its chemical stability under combined radiation and aqueous exposure has been validated in cyclotron target service, where Medina et al. [13] documented the behaviour of Havar® foil under high-current proton irradiation, reporting maintained structural integrity and no detectable corrosion-induced degradation of the beam window after extended irradiation cycles at proton beam currents relevant to commercial isotope production.

Wiklund et al. [9] examined corrosion resistance of cobalt-chromium alloys in biological environments, demonstrating that surface condition and preparation are as significant as bulk composition in determining passive film stability — a finding with direct relevance to the post-processing and cleaning protocols applied to all three alloys in medical device manufacture.

6. Oxidation Resistance

All three alloys derive their oxidation resistance primarily from their chromium content, which promotes the formation of a dense, adherent Cr_2O_3 (chromia) surface layer acting as a diffusion barrier against further oxygen ingress. Young [19] provides a comprehensive treatment of high-temperature oxidation mechanisms in chromia-forming alloys, establishing that the growth kinetics of the Cr_2O_3 layer follow a parabolic rate law controlled by solid-state diffusion of chromium and oxygen through the scale, and that alloy additions of W and Mo influence the defect chemistry of the scale and hence its protective effectiveness.

Havar® demonstrates good oxidation resistance up to approximately 800°C in air. Its tungsten addition stabilises the chromia layer at elevated temperatures by reducing the chromium diffusivity in the alloy matrix, thereby slowing chromium depletion at the alloy-scale interface and extending the period of protective oxidation — a mechanism consistent with the behaviour of tungsten-bearing cobalt alloys reviewed by Gleeson [18].

Elgiloy® and Phynox® exhibit effective passive film stability up to approximately 600–650°C in air. Their higher molybdenum content, while beneficial for aqueous corrosion resistance, contributes to the formation of volatile MoO_3 above 700°C, which may locally disrupt the protective oxide layer. This behaviour is well-established in the high-temperature corrosion literature and is discussed in the context of Mo-bearing alloys by Gleeson [18].

In vacuum and inert atmosphere environments, surface oxidation is suppressed and all three materials perform reliably without surface degradation across their respective service temperature ranges. For ultra-high vacuum applications, low outgassing rates following vacuum baking are confirmed for Havar® ($<10^{-10}$ torr·L/(s·cm^2)), with comparable behaviour expected for Elgiloy® and Phynox® given their similar compositions. Where service conditions involve cyclic oxidation, all three alloys exhibit good resistance to oxide spallation owing to the close thermal expansion match between the chromia layer and the alloy substrate. Prolonged cyclic exposure above 600°C may lead to progressive chromium depletion at the surface, and protective coatings or inert atmosphere processing should be considered in such conditions.

7. Biocompatibility

All three alloys are considered biocompatible and have been used in medical device applications, though important distinctions exist. Okazaki and Gotoh [10] conducted a systematic in vitro comparison of metal ion release from a broad range of metallic biomaterials including cobalt-chromium alloys, demonstrating that Co-Cr-Mo and Co-Cr-Ni-Fe alloys release significantly lower concentrations of cytotoxic ions compared to Ti-6Al-4V in aggressive simulated body fluid conditions, supporting the biological safety profile of the alloy family as a whole.

Phynox® was specifically developed as a beryllium-free alternative to Elgiloy®, addressing beryllium's known toxicity and classification as a potential carcinogen during processing. Phynox® has become the preferred alloy for implantable devices in European markets and carries the most comprehensive biocompatibility characterisation under ISO 10993 [17]. Elgiloy® has an extensive clinical track record in cardiovascular applications — most notably surgical stents and guidewires — with fatigue data supporting its use under the cyclic loading conditions of cardiovascular implants as documented by Marrey et al. [6], and is specified under ASTM F562-13 [16] and ASTM F1058-16 [21] for surgical implant applications. Its beryllium content requires strict occupational health controls during fabrication and machining.

Hallab et al. [11] examined metal sensitivity in patients with orthopaedic implants, reporting that cobalt and chromium ion hypersensitivity, while rare, represents a clinically relevant consideration in long-term implant design. This work underscores the importance of passive film stability — and hence the corrosion and surface preparation standards applied to all three alloys — in minimising metal ion release over extended implant service life. Wataha [7] provides a broader review of methods for predicting biological responses to dental and orthopaedic materials, establishing the electrochemical and surface characterisation frameworks most applicable to cobalt-chromium alloy qualification.

Havar® is biocompatible and has been used in MRI-compatible components and precision medical springs. However, it is less extensively characterised against implantable medical device standards than Elgiloy® or Phynox®, and its primary medical application domain remains cyclotron target windows and isotope production rather than direct implantation.

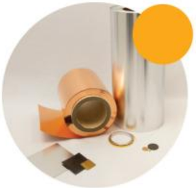
8. Nuclear Physics & Isotope Production Applications

Havar®'s application as a cyclotron target window material is its most distinctive use case and the subject of substantial scientific investigation. Tárkányi et al. [1] measured excitation functions for proton-induced reactions on Havar®, copper, and aluminium foils, providing the nuclear cross-section data required for accurate beam energy and intensity monitoring in cyclotron target systems. Their work established Havar® as a reference monitor foil material for proton beam characterisation across the energy range relevant to medical isotope production (10–30 MeV).

Spahn et al. [2] extended this work with cross-section measurements for proton-induced reactions on Havar® foils at energies specifically relevant to ^{18}F, ^{64}Cu, and ^{68}Ga production, confirming that the nuclear activation products generated within the Havar® window itself are manageable and do not compromise target purity or personnel dose rates at typical production beam currents. This work is foundational to the regulatory acceptance of Havar® windows in GMP-certified isotope production facilities.

Blessing et al. [3] investigated target window foil materials for high-current cyclotron beams, comparing Havar® against alternative window materials including titanium and aluminium alloys. Their analysis demonstrated that Havar®'s combination of high tensile strength, low thermal expansion, and adequate thermal conductivity provides a superior window lifetime under high beam current conditions, where thermal stress and fatigue cycling from beam-on/beam-off cycles are the primary failure mechanisms.

Medina et al. [13] characterised Havar® foil behaviour under high-current proton irradiation in a production environment, confirming maintained structural integrity and measuring the temperature distribution across the foil during irradiation. Their thermal modelling demonstrated that Havar®'s thermal conductivity and yield



strength at elevated temperature are sufficient to prevent foil rupture under continuous beam currents of up to 80 μA when adequate coolant flow is maintained on the downstream face of the window.

The broader context of nuclear activation cross-section data for cyclotron target monitoring is reviewed by Hermanne et al. [14], whose assessed nuclear data compilation provides the definitive reference for Havar® foil use as a beam monitor in the energy range 5–65 MeV. The stopping power of Havar® for protons, evaluated using the theoretical framework of Seltzer and Berger [12], is an essential input to target design calculations and beam energy degradation modelling.

9. Fabrication & Processing

CHARACTERISTIC	*HAVAR®*	*ELGILOY®*	*PHYNOX®*
AGE HARDENING TEMPERATURE	*538°C (1,000°F)*	*482°C (900°F)*	*500°C (930°F)*
MIN. COLD WORK FOR PEAK PROPERTIES	*80%*	*37%*	*37%*
MIN. BEND RADIUS (90°)	*8× THICKNESS*	*5× THICKNESS*	*5× THICKNESS*
WELDABILITY	*EB / LASER*	*EB / LASER / TIG*	*EB / LASER / TIG*

Table 4 — Fabrication Characteristics

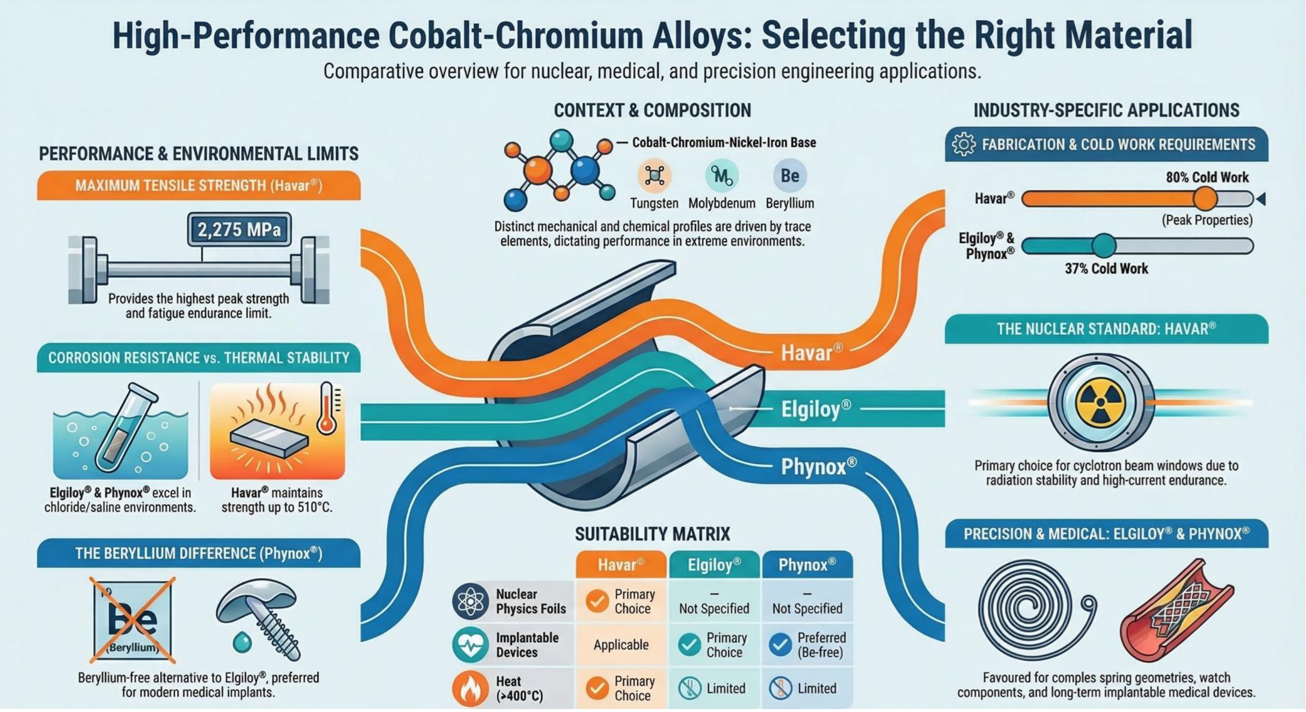
Havar® requires a minimum of 80% cold work to develop peak mechanical properties, demanding more intensive processing relative to Elgiloy® and Phynox®, both of which respond well to age hardening after approximately 37% cold reduction. Havar®'s higher carbon content and work-hardening rate result in stiffer forming behaviour, requiring larger bend radii (minimum 8× material thickness for 90° bends) and more robust tooling. Elgiloy® and Phynox® are generally more formable, which is reflected in their broader use in complex spring geometries and coiled medical device components.

All three alloys can be joined by electron beam and laser welding. Elgiloy® and Phynox® are additionally amenable to TIG welding, offering greater flexibility in joining applications. The beryllium content of Elgiloy® requires fume extraction and appropriate occupational health controls during all welding and machining operations.

10. Application Suitability Summary

APPLICATION	HAVAR®	ELGILOY®	PHYNOX®
CYCLOTRON TARGET WINDOWS	✓✓✓	—	—
NUCLEAR PHYSICS FOILS	✓✓✓	—	—
ULTRA-THIN FOIL (<25 μM)	✓✓✓	✓	✓
PRECISION SPRINGS	✓✓	✓✓✓	✓✓✓
IMPLANTABLE MEDICAL DEVICES	✓	✓✓✓	✓✓✓
MRI-COMPATIBLE COMPONENTS	✓✓✓	✓✓✓	✓✓✓
CHLORIDE CORROSION RESISTANCE	✓✓	✓✓✓	✓✓✓
ELEVATED TEMPERATURE (>400°C)	✓✓✓	✓	✓
PRESSURE DIAPHRAGMS	✓✓✓	✓✓	✓✓
WATCH & INSTRUMENT SPRINGS	✓	✓✓✓	✓✓✓
BERYLLIUM-FREE FABRICATION	✓	—	✓
UHV / HERMETIC BARRIERS	✓✓✓	✓	✓

Table 5 — Application Suitability (✓✓✓ Primary; ✓✓ Suitable; ✓ Applicable with limitations; — Not typically specified)



High-Performance Cobalt-Chromium Alloys: Selecting the Right Material

Comparative overview for nuclear, medical, and precision engineering applications.

PERFORMANCE & ENVIRONMENTAL LIMITS

MAXIMUM TENSILE STRENGTH (Havar®)

2,275 MPa

Provides the highest peak strength and fatigue endurance limit.

CORROSION RESISTANCE vs. THERMAL STABILITY

Elgiloy® & Phynox® excel in chloride/saline environments.

Havar® maintains strength up to 510°C.

THE BERYLLIUM DIFFERENCE (Phynox®)

Beryllium-free alternative to Elgiloy®, preferred for modern medical implants.

CONTEXT & COMPOSITION

— Cobalt-Chromium-Nickel-Iron Base

Distinct mechanical and chemical profiles are driven by trace elements, dictating performance in extreme environments.

SUITABILITY MATRIX

	Havar®	Elgiloy®	Phynox®
Nuclear Physics Foils	✓ Primary Choice	— Not Specified	— Not Specified
Implantable Devices	Applicable	✓ Primary Choice	✓ Preferred (Be-free)
Heat (>400°C)	✓ Primary Choice	Limited	Limited

INDUSTRY-SPECIFIC APPLICATIONS

FABRICATION & COLD WORK REQUIREMENTS

Havar® 80% Cold Work (Peak Properties)

Elgiloy® & Phynox® 37% Cold Work

THE NUCLEAR STANDARD: HAVAR®

Primary choice for cyclotron beam windows due to radiation stability and high-current endurance.

PRECISION & MEDICAL: ELGILOY® & PHYNOX®

Favoured for comples spring geometries, watch components, and long-term implantable medical devices.

11. Conclusions

Havar®, Elgiloy®, and Phynox® share a common property foundation — high strength, non-magnetic behaviour, corrosion resistance, and biocompatibility — while exhibiting meaningful differences that drive their respective application domains. The scientific literature reviewed here provides a robust evidence base for the distinctions between these alloys and supports the following conclusions:

Havar® is the alloy of choice where maximum tensile strength, elevated-temperature stability, oxidation resistance above 400°C, ultra-thin gauge availability, and radiation-stable performance under proton irradiation are the primary requirements. Its established role in cyclotron target windows — supported by cross-section data from Tárkányi et al. [1], Spahn et al. [2], and Medina et al. [13] — reflects a performance envelope that the other two alloys cannot replicate.

Elgiloy® offers the broadest product form availability and an extensive clinical track record in implantable medical devices, with fatigue life data [6] supporting its use in cardiovascular applications, though beryllium content requires careful process management. Phynox® addresses this limitation as a beryllium-free alternative and is increasingly the preferred specification for new implantable device designs in regulated medical markets under ISO 10993 [17] and ISO 5832-7 [15] frameworks.

For precision spring applications, watch components, long-term implantable devices, and applications in chloride environments, Elgiloy® and Phynox® represent the more appropriate choice. In contrast, Havar® offers superior performance for nuclear physics applications, ultra-high vacuum systems, medical isotope production, and demanding thin-gauge applications where exceptional strength is required.

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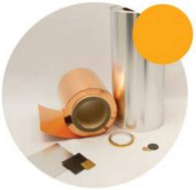

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