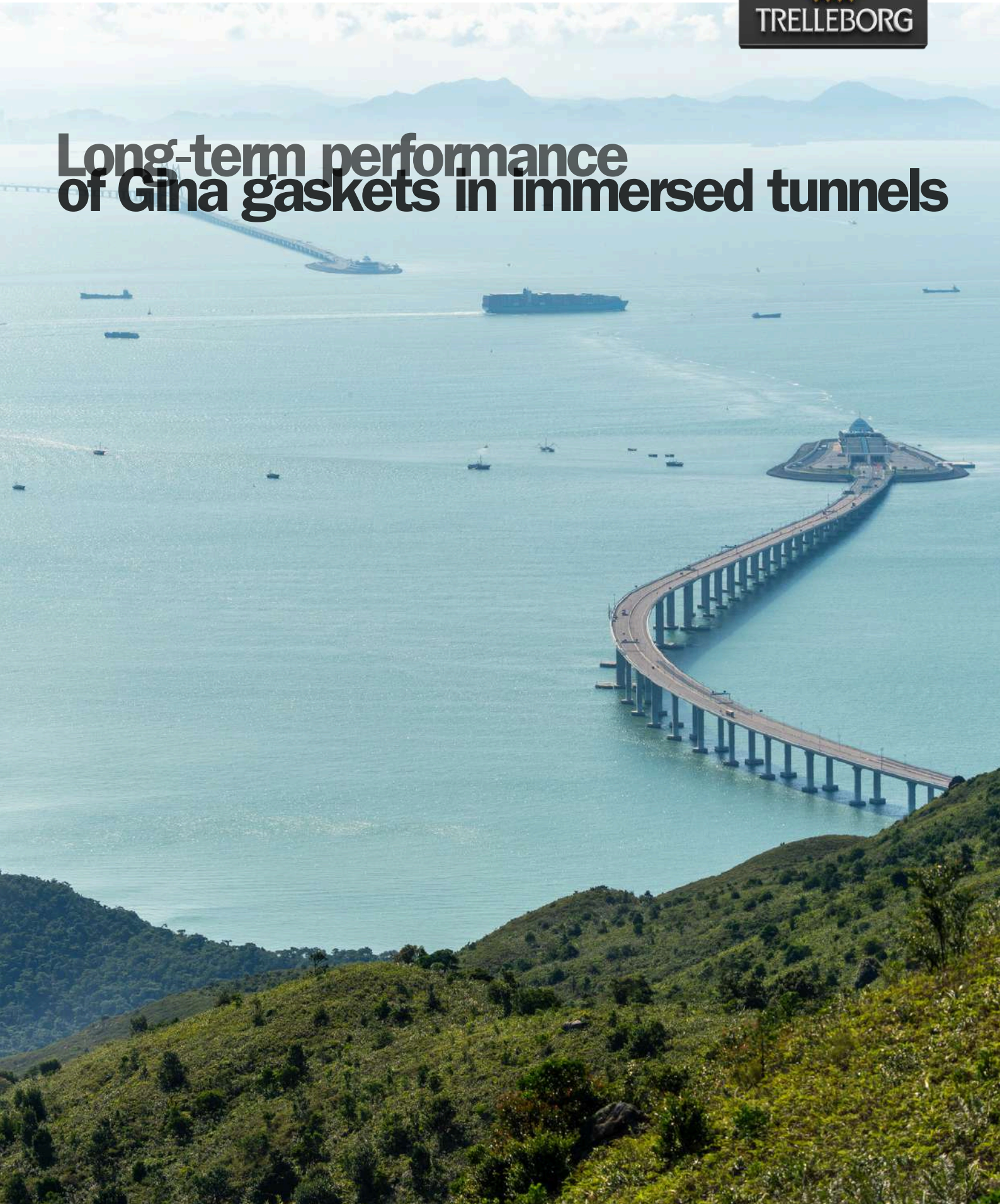




Long-term performance of Glna gaskets in immersed tunnels



ABSTRACT: Recent discussions on ageing and life prediction of immersed tunnel sealing systems have increased the need for clear, technically robust substantiation of long-term functional performance. This paper presents a consolidated technical assessment of the ageing mechanisms, design life prediction, and field performance of Trelleborg Gina gaskets, with specific focus on meeting state-of-the-art immersed tunnel design life requirements of 120 years and beyond. The paper builds on earlier Trelleborg publications and integrates accelerated ageing studies, modern Gina design methods, independent third-party investigations and long-term in-situ observations. The presented evidence demonstrates that, when designed, manufactured, and applied within a properly engineered immersion joint, Trelleborg Gina gaskets provide predictable and durable watertight performance consistent with current industry requirements for long-life tunnel infrastructure.

Contents

Sealing System for Immersed Tunnels

Introduction	3
Gina gasket in the immersion joint	3
Material formulation and ageing mechanism	3
Gina design using numerical methods	4
Predicting Gina design life	4
Independent verification and field evidence	5
Implication to long-term asset performance	5
Conclusion	6
References	6

1- INTRODUCTION

Immersed tunnels represent critical infrastructure assets for which long-term reliability and water ingress protection are essential. Over the past decades, design life requirements have progressively increased, with 120 years now widely adopted as a baseline for new projects. As a consequence, attention has shifted from initial performance validation toward substantiated, long-term design life assessment of key components, including critical sealing systems.

Gina gaskets have been applied in immersed tunnels for many decades, during which Trelleborg has built extensive track record for Gina design, production, testing and installation in immersed tunnel projects across the world (van den Brink & Razzaghighaleh, 2025). Recent academic and technical publications have contributed to broader discussions on ageing mechanisms of rubber seals, highlighting the need to clearly articulate how laboratory findings, field observations and design methods are combined to form reliable design life predictions. This paper responds to that need by presenting a technical foundation that substantiates how Trelleborg Gina gaskets comply to state-of-the art design life requirements for immersed tunnel applications.

2- GINA GASKET IN THE IMMERSION JOINT

The Gina gasket forms the primary external seal of the immersion joint, preventing water ingress during and after immersion of tunnel elements (Figure 1). Watertightness is achieved following generation of adequate local contact pressure through compression of the gasket between two adjacent tunnel element steel end frames. Sealing performance is governed by the interaction of Gina geometry, material properties, locally generated contact stresses, friction and joint opening and closing boundary conditions.

The interaction of different parameters is fundamental when considering long-term performance of the Gina gasket. Material properties alone do not ensure watertightness; instead, residual contact pressure under realistic deformation and ageing conditions governs performance. Consequently, evaluation of design life must consider the complete immersion joint.

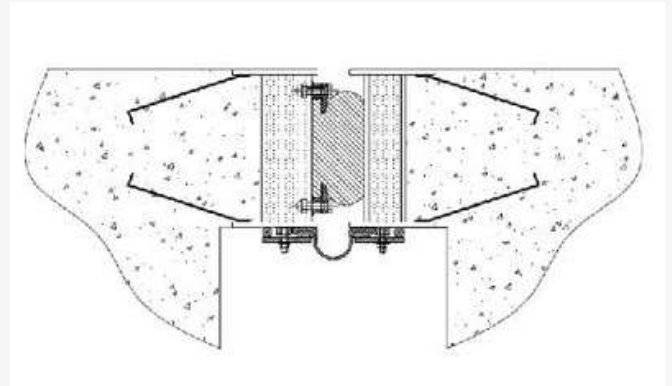


Figure 1: Typical immersion joint cross-section including a Gina gasket and an Omega seal

3- MATERIAL FORMULATION AND AGEING MECHANISMS

3.1. Material concept

Trelleborg Gina gaskets for immersed tunnel applications are based on specifically designed rubber compounds engineered for high elasticity, resilience, tear resistance, ozone resistance and minimal long-term stress relaxation under sustained compression. These rubber compounds have strong track record in civil and offshore applications where large deformations, cyclic loading and long-term performance is required.

3.2. Physical ageing: stress relaxation and compression set

From installation onwards, the Gina gasket is subjected to varying levels of sustained compression. Due to viscoelastic material behaviour, internal stresses relax over time. This stress relaxation follows a logarithmic relationship with time, with a decreasing rate of change as exposure progresses. This phenomenon is well established in the literature (Gent, 2011) and is explicitly accounted for during Gina design.

Compression set and stress relaxation do not represent sudden degradation mechanisms, but gradual and predictable changes. When evaluated in relation to sealing functionality, these effects primarily influence residual contact pressure, which is designed to remain adequate for watertightness well beyond the project required design life.

3.3. Chemical ageing: thermo-oxidative processes

Chemical ageing of rubber is primarily driven by thermo-oxidative reactions affecting polymer chains and cross-link structures (Lindley, 1992). The rate of these reactions depends strongly on temperature and oxygen availability. In thick rubber components such as Gina gaskets, oxygen diffusion into the material is severely limited, resulting in diffusion-controlled ageing.

As a consequence, measurable ageing effects are predominantly confined to the outer surface of the Gina gasket, while the bulk of the material ages at significant slower rate (Lindley, 1992). At the same time, the bulk of the material is primarily responsible for load transfer and drives sealing performance. This surface- to-core gradient is a key factor in interpreting accelerated ageing results and extrapolating them to field conditions.

4- GINA DESIGN USING NUMERICAL METHODS

Modern design and performance assessment of Gina gaskets increasingly rely on advanced hyperelastic finite element modelling (FEM) of the immersion joint. These analyses allow explicit evaluation of local contact stresses, rotations, deformation modes and the influence of geometric tolerances that cannot be captured using average stress concepts. Through detailed analysis of the contact stress in a series of simulation scenarios, the watertightness of the Gina gasket can be calculated, which is then used as an input to the numerical models to determine the Gina functional design life and demonstrate long-term performance (Mortier et al., 2026).

In this context, Gina gasket design needs to be performed on a project-specific basis, reflecting the actual geometric configuration, hydrostatic pressure, construction tolerances, load cases and environmental conditions of the individual immersed tunnel. Numerical models are tailored to the boundary conditions of each project rather than relying on generic assumptions.

This ensures that calculated contact stresses, deformation behaviour, and long-term performance directly correspond to the specific immersion joint configuration, allowing the design to demonstrably meet functional requirements over the intended design life.

5- PREDICTING GINA DESIGN LIFE

Design life prediction of Gina gaskets is based on ISO compliant accelerated ageing methodologies combined with conservative extrapolation to service temperatures using Arrhenius-type relationships (Gent, 2011). Relevant physical and mechanical properties, include:

- Hardness (ISO 7619)
- Tensile properties (ISO 37)
- Compression set (ISO 815-1)
- Stress relaxation (ISO 3384A)

These parameters are then monitored as a function of exposure time and temperature. Subsequently, end-of-life criteria are defined in functional terms, focusing on retention of sufficient material strength to ensure seal integrity and on contact pressure to ensure sealing performance.

Separate consideration is given to thin laboratory specimens and samples extracted from the interior of thick profiles, allowing the diffusion-limited character of real gaskets to be quantified. This approach avoids overly conservative predictions based solely on surface ageing and provides a realistic representation of long-term functional behaviour for immersed tunnel applications.

6- INDEPENDENT VERIFICATION AND FIELD EVIDENCE

6.1. Independent investigations

An extensive design life study on Trelleborg Gina gaskets in the context of immersed tunnel applications was performed as part of its lifecycle assessment (LCA) according to EN15804+A2. The LCA has been independently verified by third party verifiers EcoReview and MRPI, resulting in an environmental product declaration (EPD) that confirms that the rubber sealing system could achieve functional design lives of at least 120 years under realistic environmental conditions (MRPI, EcoReview, 2025). Multiple Trelleborg specific Gina rubber compounds were investigated across a range of hardnesses.

Accelerated ageing tests in air and water, combined with stress relaxation measurements and Arrhenius analysis, demonstrated that bulk material ageing progresses very slowly at service temperatures. After application of conservative safety factors, the expected minimum functional service life was found to exceed 120 years, with substantial additional margin.

6.2. Extracted in-situ Gina samples

Further substantiation can be drawn from examination of Gina gasket samples recovered from existing tunnels after several decades of service (van den Brink & Razzaghighaleh, 2025). Samples retrieved from the Rotterdam metro tunnel after more than 60 years showed limited hardness increase confined to exposed surfaces and retention of mechanical properties well within functional ranges. In addition, stress relaxation measurements on the extracted samples showed strong agreement with the design models, validating Gina design methodology (Figure 2).

When these observations are combined with accelerated ageing data, the consistency between laboratory models and field behaviour provides strong validation of the adopted life prediction methodology.

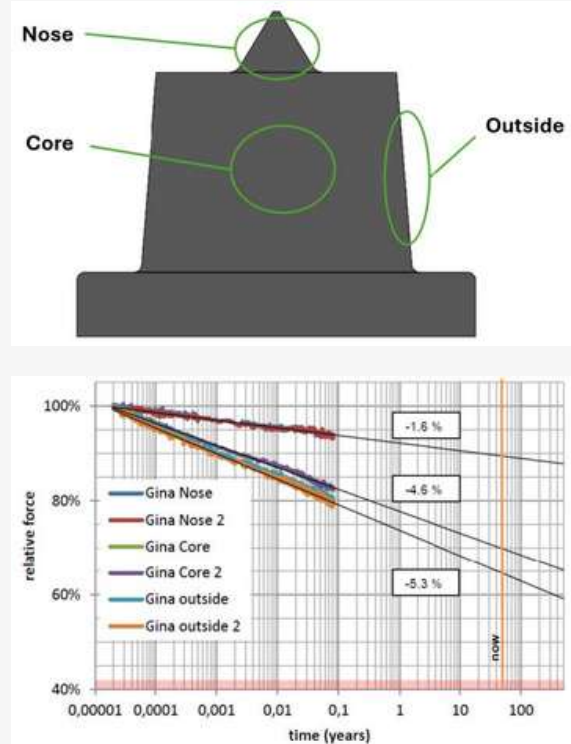


Figure 2: Measured stress relaxation of in-situ extracted Gina gasket sample after 60 years life

7- IMPLICATIONS TO LONG-TERM ASSET PERFORMANCE

Gina gaskets are designed and installed as inaccessible components within the immersion joint and do not rely on routine maintenance or replacement during the operational life of the tunnel. As such, their long-term performance must be assured at the design stage and substantiated through reliable prediction, testing and verification methods, rather than mitigated through inspection or intervention.

From an asset management perspective, a well-founded understanding of long-term Gina behaviour is therefore essential when assessing residual lifetime, life extensions, or long-term operational risk. This includes understanding how ageing mechanisms, stress relaxation and joint deformation interact over time such that it can be assessed how these effects influence residual sealing capacity at system level.

The combination of project-specific conservative advanced numerical design methods, reliable design life prediction, independent third-party verification and direct field evidence from long-serving tunnels provide a robust and defensible technical basis for such assessments. Together, these elements allow asset owners and designers to evaluate long-term performance with confidence, demonstrating that functional requirements can be maintained over the intended design life without reliance on maintenance or replacement strategies for the Gina.

8- CONCLUSION

Evaluation of long-term sealing performance requires more than isolated test results; it depends on the consistent alignment of material behaviour, system response, and observed field performance. The evidence presented in this paper brings together these perspectives, providing a balanced and technically grounded basis for conclusions on the design life Gina gaskets for immersed tunnel applications.

- The physical and chemical ageing mechanisms governing Gina gaskets are well understood and progress slowly under immersed tunnel conditions.
- Project-specific Gina design methods using hyper elastic finite element analyses and numerical models demonstrate that adequate contact pressure for watertightness is retained even when material degradation over the design life is conservatively accounted.
- Design life investigations conducted by third-parties confirm design lives exceeding 120 years even when conservative boundary conditions are applied.
- Field observations from Gina samples extracted from long-serving tunnels are consistent with laboratory-based design life prediction models.
- As inaccessible, non-maintainable critical components, Gina gaskets require long-term performance to be assured at design stage and should provide a basis to which residual lifetime can be evaluated in an asset-management context.

Taken together, these findings demonstrate that Trelleborg Gina gaskets, when applied within a properly engineered immersion joint, are technically capable of meeting state-of-the-art immersed tunnel design life requirements of 120 years and beyond.

9- REFERENCES

- Van den Brink, N.W., Razzaghighaleh, M. (2025). Rubber gasket trends: Advanced watertight solutions for Immersed tunnels. 6° Congresso Brasileiro de Túneis e Estruturas Subterrâneas.
- Gent, A.N., (2011). Engineering with Rubber (3rd ed.). Hanser Publications.
- Lindley, P.B., (1992). Engineering design with natural rubber (5th ed.). The Malaysian Rubber Producers' Research Association
- Mortier, H., van den Brink, N.W., Johansson, C., van Putten, E. (2026). Alternative design verification for large Gina gaskets. ITA-AITES WTC 2026 Montréal
- MRPI, EcoReview. (2025). Gina gasket MRPI® -EPD Certificate according to EN15804+A2., MRPI Registration: 1.1.00783.2025.

DISCLAIMER

The information in this paper is considered to be true and correct at the date of publication, changes in circumstances and regulations after the time of publication may impact the accuracy of the information. The Information may change without notice and Trelleborg is not in any way liable for the accuracy of any information printed and stored or in any way interpreted and used by a user.

**© TRELLEBORG AB, PO BOX 153, 231 22
TRELLEBORG, SWEDEN.**

This technical paper is the copyright of Trelleborg AB and may not be reproduced, copied or distributed to third parties without the prior consent of Trelleborg AB in each case.





Trelleborg is a world leader in engineered polymer solutions that seal, damp, and protect critical applications in demanding environments. Its innovative solutions accelerate performance for customers in a sustainable way.

Trelleborg Marine and Infrastructure is a leading provider of premium solutions for critical marine, port, and built infrastructure applications. Its innovative polymer and smart technology solutions enhance operational efficiency, safety, and sustainability.

WWW.TRELLEBORG.COM/MARINEANDINFRASTRUCTURE



LinkedIn: [Linkedin.com/company/trelleborg-marine-and-infrastructure](https://www.linkedin.com/company/trelleborg-marine-and-infrastructure)

YouTube: [Youtube.com/c/TrelleborgMarineInfrastructure](https://www.youtube.com/c/TrelleborgMarineInfrastructure)

Facebook: [TrelleborgMarineandInfrastructure](https://www.facebook.com/TrelleborgMarineandInfrastructure)

Twitter: [@TrelleborgMI](https://twitter.com/TrelleborgMI)

Trelleborg Marine and Infrastructure

Email: marine_infra@trelleborg.com