Metal-to-metal contact GEM gaskets for nuclear applications

Graphite is widely used in sealing because of its high mechanical strength, thermal stability, compressibility, chemical compatibility, and low-leakage performance. It is usually used with a metallic structure where the graphite performs the sealing function (like grooved, corrugated, spiral-wound gaskets, etc). Among these gaskets, GEM ("Graphite Expansé Matricé", which means stamped expanded graphite) gaskets are a special development for the French nuclear industry.

By Jane Abi Aad PhD

GEM gaskets consist of two different elements: a die-formed expanded graphite ring and a metallic ring. The graphite rings are manufactured as follows (Figure 1).
A graphite tape is cut and then wound around a mandrel which is positioned in a mould. Then pressure is applied to compress the rings. The mandrel, the mould, the compression, and the graphite quantity are calculated by the supplier according to the GEM groove dimensions.
The graphite ring, which is the flexible part of the gasket, will perform the sealing function. The metallic ring, which can be made from different metals, is made mostly from stainless steel. This metallic ring is the compression stop as it comes into contact with the flange faces.
There are two different designs depending on suppliers:

1. The first one is composed of two graphite rings inserted into calibrated grooves in the metal ring (Figure 2)
2. The second one is composed of a graphite ring positioned between two metallic rings (inner and outer rings) (Figure 3).

Both designs operate on the same principle: once the metal-to-metal contact is reached, the seal is tight. Die-formed graphite rings are compressed to the suitable calculated density by its designer to achieve the needed tightness.
In the case of assemblies subjected to extreme service conditions, this type of gasket prevents the application of excessive load on the graphite seal during thermal and pressure cycling.

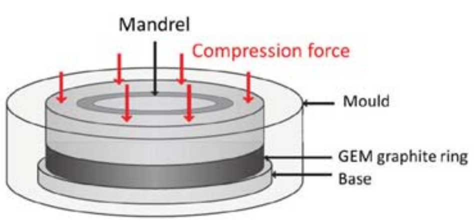

Figure 1. Tooling schematic for graphite ring production

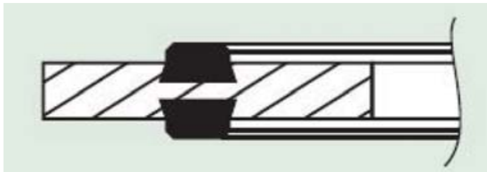

Figure 2. GEM gasket design with grooves

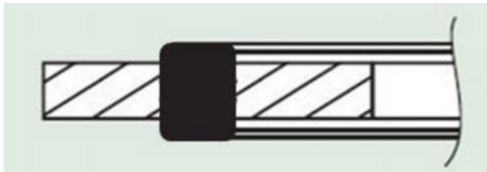

Figure 3. GEM gasket design with two metal rings

Toughest applications

GEM gaskets (Figure 4) can be used in multiple areas but are, most of the time, reserved for the toughest applications involving high pressure and/or, temperature. The main industries are energy, nuclear, petrochemical, defence, chemistry, metallurgy, etc. For example, on the primary and secondary circuits of EDF's thermal and nuclear plants, most of the gaskets that have been used in the past were spiral wound gaskets with asbestos winding as the sealing element. They were assembled in a groove to ensure metal-to-metal contact as soon as the seal is sufficiently

Figure 4. GEM gasket types

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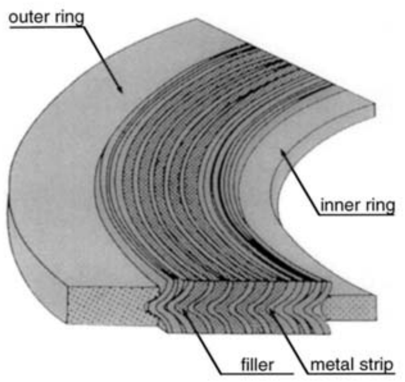

Figure 5. Configuration of a spiral wound gasket

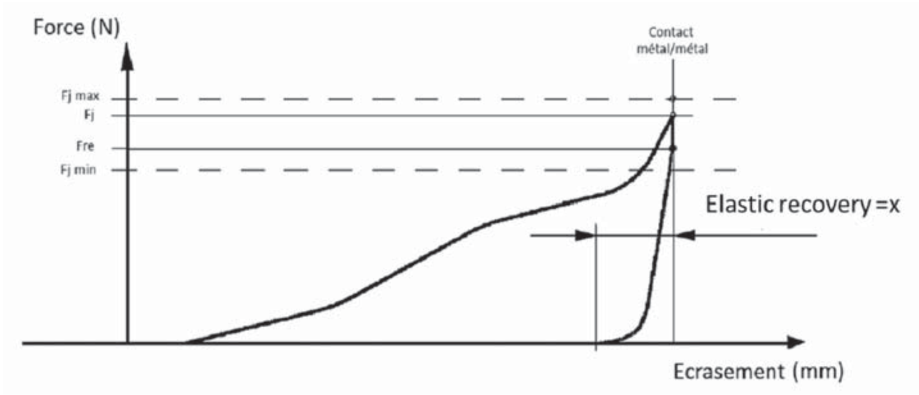

Figure 7. Load as a function of the thickness of the gasket (Source: EDF specification)

tight. This contact prevents excessive crushing of the seal in case of severe overtightening due to human error or because of sudden changes in service conditions.
However, spiral wound gasket flange connections account for a high proportion of all leakage incidents. Even though graphite is a superior sealing material in SWG's, there still are significant problems with this design of seal.

Poor reproducibility

Characteristics of the spiral wound gaskets were demonstrated through many tests (mainly, compression tests) to have a poor reproducibility (Figure 6). The variability in the performance is due to many parameters such as winding density, material receipt inspection and storage which might damage the gasket seating surface or different machines developed for the manufacturing of these gaskets leading to different characteristics.
For all the above listed reasons, EDF investigated GEM gaskets with expanded graphite without metal strips. They have very reproducible tightness and compression characteristics, with low seating stress and good elastic recovery.

Moreover, these gaskets can support a very high seating load. Since the performance of the gasket depends on the compression of the graphite in the groove, it is protected by the two metal rings and cannot be compressed anymore once the metal-to-metal contact is reached. This is a very important criterium for the technicians torqueing on site.

EDF- specifications

However, graphite spiral-wound gaskets cannot fully be replaced by GEM gaskets since the latter are expensive and limited in dimensions. In fact, the graphite ring is die-formed, and requires very high loads for bigger diameters. Many studies were conducted to deepen EDF's knowledge on the functioning of the GEM gaskets and most importantly to write specifications for the manufacturing of these gaskets to secure the installation in nuclear plants. The technical operational unit of EDF has written and updated specifications for GEM gaskets. These documents were not significantly modified for more than 20 years.
We can mention two types of specifications:

(1) CSCT : Cahier des Spécifications et Conditions Techniques de pièces de rechange (covering mechanical and sealing characteristics of GEM gaskets, and the materials to be used to manufacture these gaskets)
(2) CSCP : Cahier des Spécifications et Conditions Particulières de pièces de rechanges (covering marking, packaging, shipment, purchasing and system management)

Two types of tests

By focusing on the tests required for these gaskets, we can note two types: qualification tests (done at the very first step to validate and qualify the supplier and its products) and follow-up tests to be done for each order (quality control tests).

1) Qualification tests: there are two different programs for primary and secondary circuits under conditions simulating real service conditions. The mechanical resistance of the outer ring and the sealing of the gasket (at loading and unloading) are tested following various test procedures and under different test conditions.
2) Quality control tests: they consist of compressing the gasket (compression at a defined rate and period) until obtaining the thickness corresponding to the metal-to-metal contact. Afterwards, the gasket is unloaded during a fixed duration (Figure7).

The parameters which must be verified are:

- Fjmin < Fj < Fjmax
- Fre ≥ 0.9 Fj
- X: elastic recovery

Fjmax: maximum seating stress not to be exceeded, indicated in the calculation note. This force is the upper limit of Fj at the initial compression.
Fj: stress corresponding to the initial compression of the seal to obtain metal/metal contact.
Fre: residual reaction force of the gasket after relaxation, i.e., one hour of constant compression simulating metal/metal contact. When the gasket is compressed to the thickness corresponding to the metal -to-metal contact, this thickness is kept constant for one hour and the decrease in the load due to the relaxation of the gasket on its seating surfaces is recorded (Figure 8).

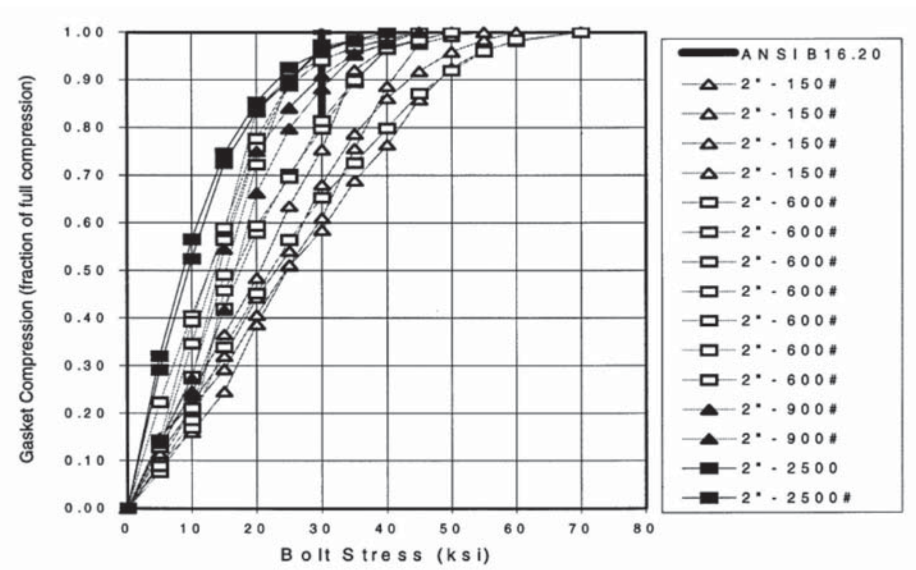

Figure 6. Load-deflection characteristics of fifteen 2-inch spiral-wound gaskets

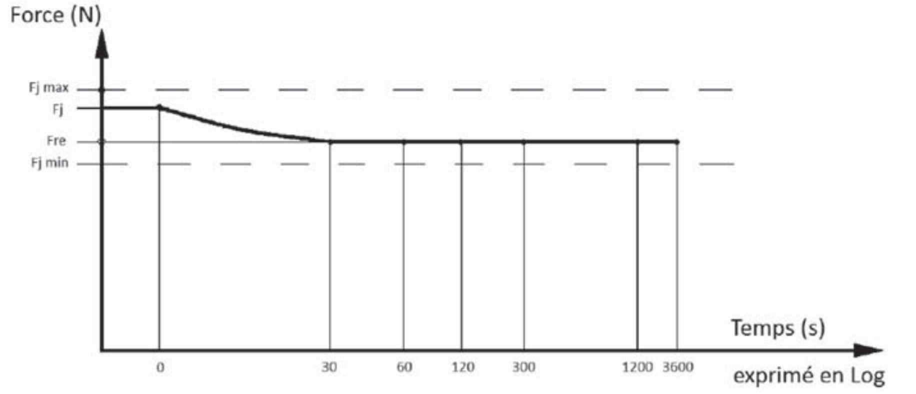

Figure 8. Diagram representing the load as a function of time (Log) (Source: EDF specification)

Upgraded method by Cetim

As we can see in Figure 7, the point indicating the reach of the metal-to-metal contact is more likely to be defined visually. When the curve trends vertically without a change in the thickness of the gasket, the technician will define the point corresponding to Fj, or to the metal-to-metal contact.
This determination is not always reliable since many different points corresponding to the metal-to-metal contact can be identified according to the person who is testing and analysing the data.
Thus, in the frame of a work force (made of end-users of EDF and suppliers), Cetim, the Technical Centre for Mechanical Industry in France, has proposed a new method based on mathematical analysis of the compression curve data to upgrade the calculations. This upgraded method of test data analysis associated to the improvements of the calculation routine will be integrated in a future revision of the RCC-M® (Règles de Conception et de Construction des Matériels Mécaniques REP = Design and construction rules of mechanical materials for pressurized water reactors) which is a French code edited by AFCEN (French Association for the rules of design, construction and monitoring of electro-nuclear boiler equipment) to ensure a high quality and security level that the monitoring of the nuclear reactors require.

More adapted tools

The methods developed allows RCC-M-users to use more adapted tools to define the torque values needed for the gaskets, and to go beyond EN-25030 (Fasteners - Threaded connections with ISO metric thread - Part 1: design rules for tensile loaded bolted joints) with an improved and adapted Taylor Forge method totally suitable for this sealing technology. It must be noted that the part of EN-1591 (Flanges and their joints. Design rules for gasketed circular flange connections), dealing with metal-to-metal contact calculations (XP CEN/TS 1591-3), has not been promoted to standard level and remains only a technical specification.
The GEM gaskets have been developed through the years to meet with the French nuclear industry's needs. Of course, this gasket is not only used by nuclear engineers, but also in many other applications. The development to improve the calculations for flange assemblies to achieve higher security and safety levels is regularly maintained and monitored.

Reference:

Lejeune, Boulben, 2017, Introduction of Gasket Testing Protocols in the New RCC-M® F7000 Revision Proposal (ASME PVP2017 – 65701)