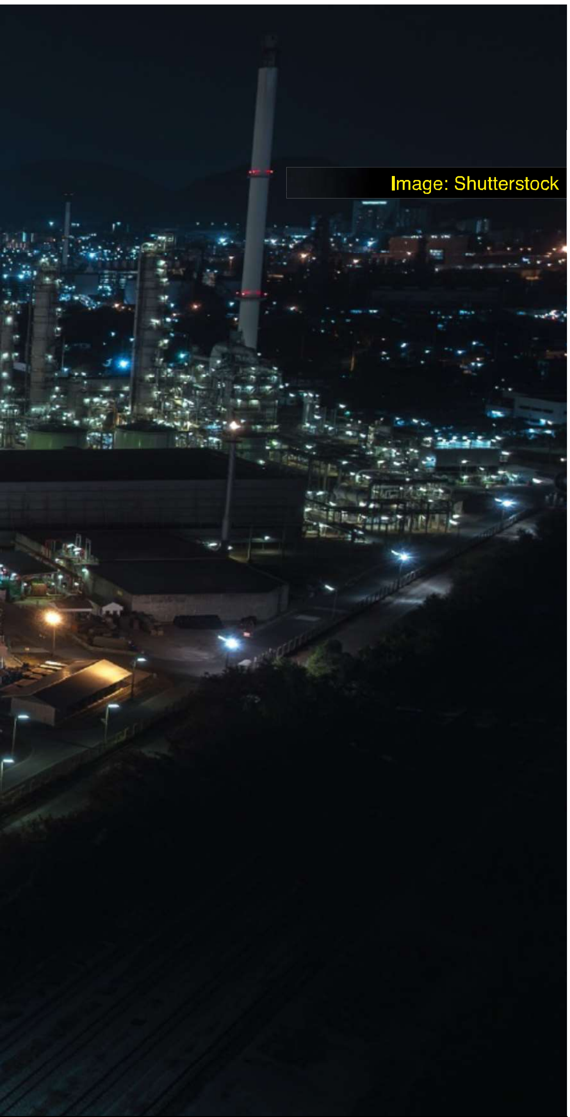
A practical, conservative for **evaluating flame damage in Ex d enclo**

Flameproof (Ex d) enclosures remain one of the most widely used explosion protection concepts for electrical equipment installed in hazardous atmospheres. Their engineering principle is well-established: an internal ignition may occur, but the enclosure is designed such that hot gases generated by combustion must pass through a flamepath narrow enough to cool and quench them before they reach the external environment.

The flamepath therefore performs a safety-critical thermal function that directly determines whether flame transmission is prevented.

IEC 60079-1 prescribes the minimum flamepath length, maximum allowable gap, surface finish requirements, and verification through non-transmission testing using hydrogen-rich mixtures. These requirements are conservative and have proven effective over decades of industrial use. However, the standard includes only a single qualitative statement regarding mechanical degradation: flamepaths must remain “free from damage”. It does not define the level of damage that is acceptable, nor does it provide quantitative criteria for interpreting the unavoidable scratches, tool marks, and minor wear commonly observed during installation, inspection, or maintenance.

This lack of guidance creates two recurring problems. First, many enclosures are rejected



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unnecessarily due to cosmetic defects that have no measurable effect on quenching performance. Second, some genuinely hazardous conditions – particularly corrosion or gap widening – may be underestimated because the Standard does not differentiate between damage types. Inspectors must therefore make judgment calls without a structured, technically grounded methodology.

The purpose of this article is to provide a

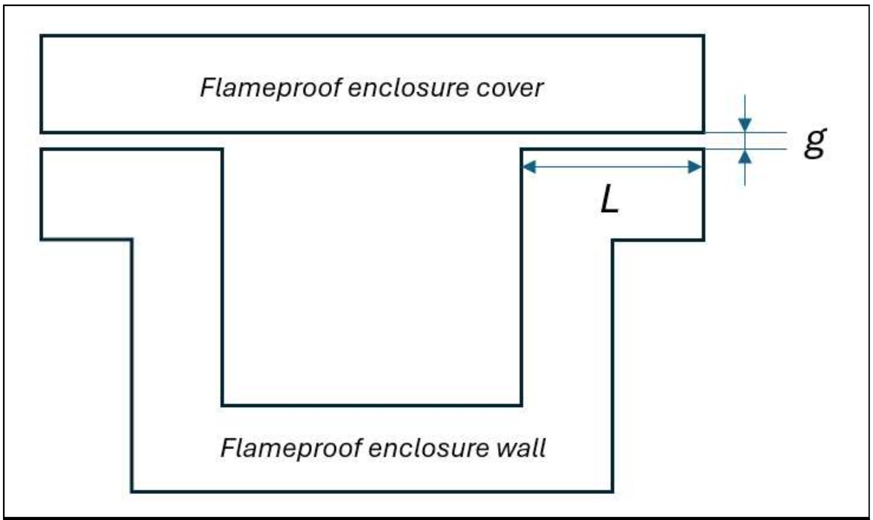

Figure 1: Typical Ex d flange-type flamepath, showing nominal length and clearance

practical, conservative, and inspection-ready evaluation framework that remains fully aligned with IEC 60079-1 while reflecting real flamepath geometry, experimental findings, and field observations. The proposed method distinguishes between length-only defects, which typically have limited impact, and widening defects, which represent the dominant risk factor for flame transmission. This distinction preserves the conservative intent of the Standard and provides a structured basis for consistent inspection decisions.

Why standards alone are not enough

IEC 60079-1 flamepath requirements assume an ideal geometry: a continuous narrow channel of prescribed length and uniform gap. In practice, however, real flamepaths – particularly flange-type joints used in most industrial Ex d enclosures – contain intentional interruptions.

Bolt-head recesses, machining steps, gasket seats, and casting tolerances regularly remove 10–15 mm of the nominal flamepath length. Despite these interruptions, certified enclosures reliably pass non-transmission tests performed using hydrogen-rich mixtures such as 37% H_2 in air.

This real-world observation highlights a crucial fact: it is the uninterrupted portion of the flamepath – not the nominal total length – that governs quenching performance. Even with recessed regions or imperfections, the actual continuous section that remains is often sufficient to cool the flame front below its ignition temperature.

Yet the Standard does not explain how to interpret damage that reduces uninterrupted length or affects surface quality without changing the gap. It treats all damage as conceptually identical, despite experimental evidence that different damage mechanisms have fundamentally different effects.

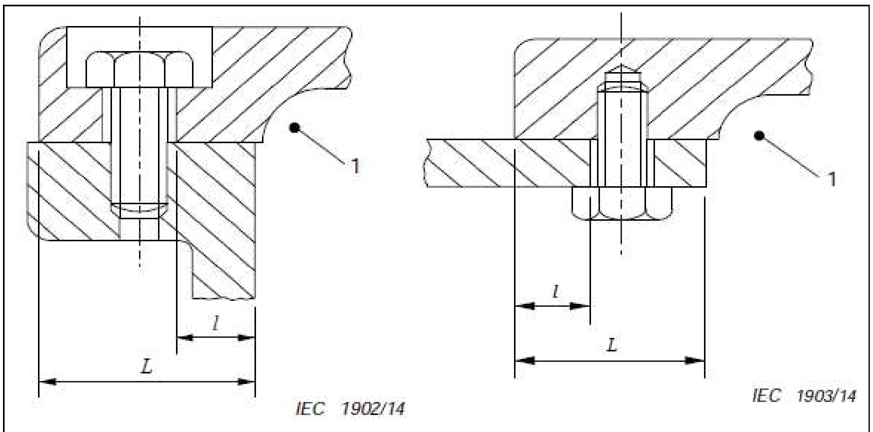

Figure 2: Interruption of the nominal flamepath caused by bolt-head recesses

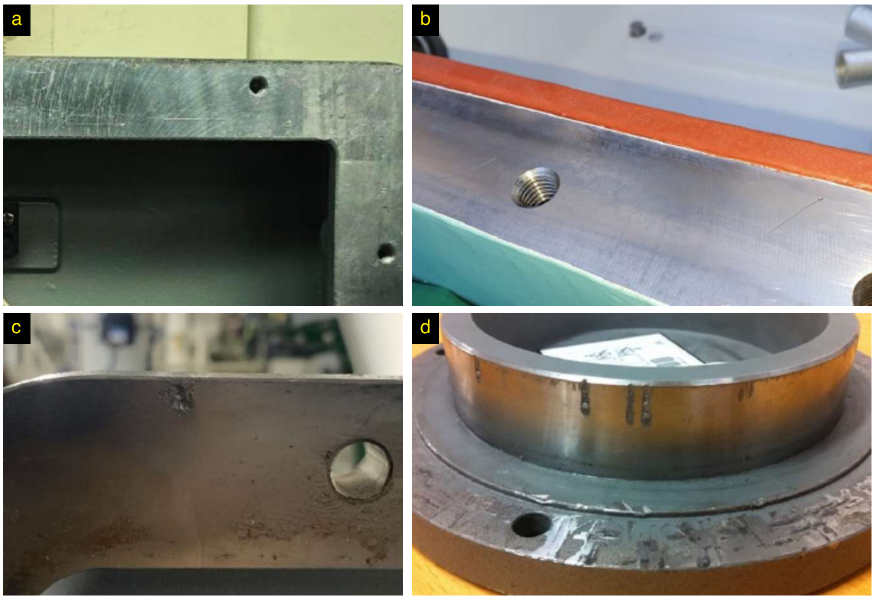

Figure 3: Common types of flamepath damage observed in field inspections. Clockwise: (a) Linear scratch, (b) Indentation, (c) Corrosion pit, (d) Gouge / material removal

This absence of clarity places inspectors in a difficult position: without structured guidance, decisions may vary widely between individuals, sites, and organisations.

A conservative, physically grounded framework is therefore needed – one that reflects how flamepaths actually behave and how damage influences quenching performance.

What experiments reveal about flamepath damage

Over the last two decades, several research groups – most notably Grov, Solheim, Arntzen, and Opsvik – have studied damaged Ex d flamepaths using standardised ignition tests. Their results converge on three essential conclusions.

First, length-only defects rarely compromise flame-arresting capability for Group IIB gases. Scratches, machining marks, shallow grooves, or minor tool damage – even when several millimetres long – did not cause flame transmission as long as the remaining uninterrupted length exceeded the minimum required by IEC 60079-1. These findings align with the inherent conservatism of the Standard, which prescribes flamepath lengths significantly greater than the quenching distances measured for typical IIB gases.

Second, gap widening is the dominant risk factor. Corrosion pits, localised roughening, gouges, and material removal increase the effective gap, reducing heat transfer and increasing the likelihood that hot gases will ignite the surrounding atmosphere. Even seemingly small widening can have disproportionate effects. Experimental results consistently show that widening – not length reduction – is the parameter most strongly correlated with transmission.

Third, IIC flamepaths – intended for hydrogen and acetylene – are significantly more sensitive to imperfections. Small defects that pose negligible risk in IIB equipment may cause transmission in IIC joints. For this reason, the framework proposed here applies strictly to IIB flamepaths and must not be extrapolated to IIC equipment.

The overall lesson from experimental work is clear: flamepath performance is governed by (1) uninterrupted length and (2) whether widening is present. Depth, by itself, is not a meaningful parameter unless it results in actual gap enlargement. This distinction is essential for a correct and conservative damage evaluation model.

Field observations from real installations

Field inspections of Ex d enclosures from petrochemical, power generation, marine, and heavy-industry applications reveal patterns consistent with the experimental results. Most industrial flamepaths have nominal lengths of 25-30mm, but only 12-18mm of continuous, uninterrupted surface due to bolt recesses and machining features. Despite this reduced effective length, the equipment performs safely because certification testing already accounts for such recesses.

Commonly observed defects include:

- Linear scratches 1–5 mm long caused by tool contact or debris
- Shallow indentations from trapped wires
- Minor casting irregularities
- Small nicks or handling marks

Such defects visually appear concerning but typically do not alter the gap or the thermal behaviour of the flamepath.

In contrast, corrosion pits – often initiated by moisture ingress – or gouges created during improper disassembly may produce localised widening. Even if the affected area is small, any measurable widening must be treated as a high-risk condition because it directly affects the quenching function. Field evidence confirms that widening defects are far more consequential than superficial length-only damage.

Conservative evaluation method

Flamepath damage can be conservatively categorised into two classes:

1. Length-only defects (no gap increase)
2. Widening defects (any measurable gap increase)

This binary classification reflects the actual physical mechanisms underlying flame quenching and aligns with experimental evidence. Depth by itself is not treated as a variable unless it results in widening.

For length-only defects, the uninterrupted effective flamepath length is:

$$L_{eff} = L_1 + L_2 - L_{damage}$$

where L_1 and L_2 are the intact, continuous flamepath segments on either side of the defect. This formulation treats the damaged region as non-functional – a conservative assumption supported by test data showing that scratches reduce surface quality but do not eliminate quenching capability of the surrounding intact regions.

To strengthen conservatism and account for manufacturing tolerances, recess interruptions, and surface variability, a reduction factor is applied:

$$L_{eff\_adj} = 0.8 \times (L_1 + L_2 - L_{damage})$$

Interpretation:

- If Leff_adj ≥ Lreq → the defect is generally acceptable for IIB equipment.
- If any measurable widening is present → length-based evaluation becomes invalid; treat as a high-risk defect.
- If the maximum allowable gap in IEC 60079-1 is exceeded → immediate rejection or rework is required.

This approach preserves the conservative intent of the standard without overstating the importance of cosmetic damage.

Practical guidance for inspectors

Length-only defects may be considered acceptable when:

- No measurable widening or pitting is present
- The surface remains smooth and continuous
- The adjusted effective length meets or exceeds Lreq
- There is no corrosion or metal loss

High-risk defects requiring corrective action include:

- Corrosion pits, roughness, or localised erosion
- Gouges or material removal affecting gap geometry
- Any measurable widening detected by feeler gauge
- Sharp-edged cavities or irregularities

Immediate rejection is required when:

- The gap exceeds the maximum permitted by IEC 60079-1
- Widening is visible or easily detectable
- Corrosion extends across several millimetres

These criteria translate the conservative physics of flame quenching into a consistent, field-applicable inspection process.

Conclusion

Length-only defects, such as superficial scratches or small handling marks, rarely compromise the flame-arresting performance of Group IIB flamepaths. In contrast, gap widening caused by corrosion, pitting, or gouging directly threatens the quenching mechanism and must be treated as a high-risk condition. The conservative effective-length method with the 0.8 adjustment factor provides a structured, physically grounded, and inspection-ready framework that improves consistency in maintenance decisions while remaining fully aligned with IEC 60079-1.

This practical distinction between harmless superficial damage and defects requiring intervention can significantly reduce unnecessary equipment replacement while avoiding underestimation of genuinely hazardous conditions and preserving the conservative design philosophy of the Ex d protection concept.■

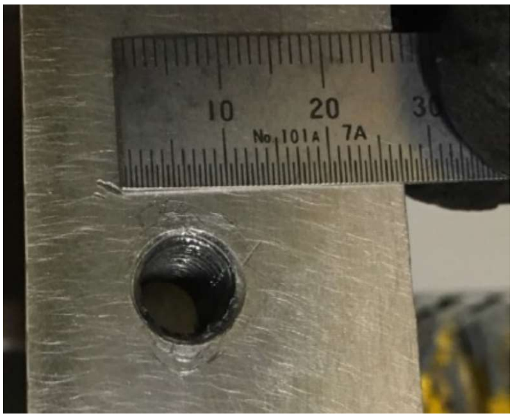


Figure 4: Field examples of superficial damage

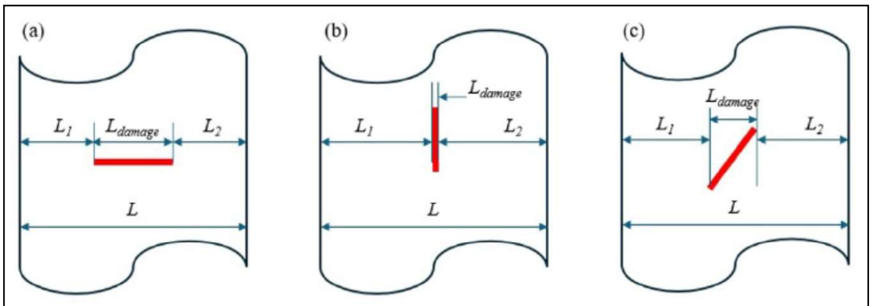

Figure 5: Effective flamepath length concept ($L_1 + L_2 - L_{damage}$)

About the author

Jeonggeun Lee is an explosion safety engineer specialising in hazardous area classification, IECEx/ATEX compliance, and practical explosion risk assessment. He works in Occupational Health and Safety at the ITER project in France, where he evaluates hydrogen and battery-related explosion hazards, performs ATEX zoning across multiple buildings, and supports ventilation and dispersion assessments for safety reviews. His role also includes developing DRPCE documentation and providing technical guidance on explosion-prevention measures during construction and commissioning activities. Before joining ITER, he worked in the South Korean shipbuilding and oil & gas industries, where he carried out Ex inspections, audits, and consultancy for manufacturers and large-scale industrial facilities. He has also served as an IECEx CoPC Trainer, delivering competency-based training for engineers and technicians in hazardous area operations.