TECHNICAL
REPORT

ISO/TR
13086-5

First edition
2022-06

Gas cylinders — Information for design of composite cylinders —

Part 5:
Impact testing of composite cylinders

Bouteilles à gaz — Informations relatives à la conception des bouteilles en matière composite —

Partie 5: Essais d'impact sur bouteilles en matière composite

Reference number
ISO/TR 13086-5:2022(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

A list of all parts in the ISO/TR 13086 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document considers how impact testing is carried out, why it is done in particular ways and the relevance of various aspects (e.g. a cylinder drop, a flying element through the air, from what direction, size, shape, weight, impact velocity, etc.; does the cylinder "fail" safe or blow into fragments with associated pressure wave?).

This document only addresses cylinders, as a definition of all the associated equipment and its interaction with the cylinders is difficult to assess. The designer can conduct some system level impact tests, including drop, to assess valves, pressure release devices and other attached components.

It is recognized that there are differences between cylinders/tubes that are for general use (without any requirements related to packaging and protection in service) and cylinders/tubes permanently mounted in frames (which offer some differences in loading and protection). Impact testing of an assembly can be different from testing a single, freestanding cylinder/tube.

This document addresses transportable cylinders, vehicle fuel containers and cylinders permanently mounted in frames. It applies to all sizes of cylinders, and to carbon, aramid and glass fibre reinforcements.

Drop testing of smaller cylinders is a requirement in some regulations, codes and standards. For serial production of automotive cylinders, an adequate returnable packing material/method to protect the cylinder during production and until mounted in the vehicle can be used. However, the drop of a cylinder demonstrates a general resistance to impact, which improves safety.

In addition to providing an understanding of the background, an overview is provided of some standard approaches to conducting tests.

Gas cylinders — Information for design of composite cylinders —

Part 5:
Impact testing of composite cylinders

1 Scope

This document provides information for the design of composite cylinders related to impact testing and service experience with impact, including:

- low energy impact, which can result from events that can occur during handling or working around cylinders;
- high energy impact, which can result from accidents during transportation, or impact by large objects with velocity;
- drop impact, which can result from handling, where cylinders are dropped or tipped over; and
- high velocity impact, which can result from high energy impact by a small object, such as gunfire, and demonstrates non-shatterability of the cylinder or tube.

Where appropriate, field experience relevant to testing requirements is provided.

NOTE Unless otherwise stated, the word “cylinder” refers to both cylinders and tubes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10286, *Gas cylinders — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10286 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

4 Low energy impact

4.1 General

Low energy impacts can occur during normal service. Examples of this include dropping tools on the cylinder, being hit by road debris, some bouncing when initiating or ending a lift by a crane, hoist, or forklift, being hit by a forklift, or similar incidents. In some cases, low energy impact can leave visual evidence of the impact or can require a cylinder to be removed from service.

4.2 Visible indications

Some impacts can be from contact with sharp objects, in which case there would likely be some visual indication of surface damage, such as a cut or surface indentation. Other impacts can be from blunt objects, which can result in some surface crazing, and either surface indentations or internal delamination, or both, without necessarily leaving visible damage. Glass fibre composite reinforcement with a translucent resin is more likely to show visible damage due to impact. Acoustic Emission Testing (AET) or Modal Acoustic Emission (MAE) can be appropriate to assess damage if there is no visible damage.

Low energy impact can cause some reduction in strength, but it is unlikely to result in a rupture when the impact occurs or before the opportunity for inspection. Guidance on these issues is provided in standards on visual inspection (see Clause 9).

4.3 Concepts in standards

4.3.1 General

There are some common low energy impact levels that are used in standards, including 30 J, 488 J and 1 200 J. These energy levels are based on typical events that can occur in service. Information related to low energy impact testing is provided in Annex A.

4.3.2 30 J impact level

The 30 J impact level is based on impact from road debris, such as one that can impact a natural gas or hydrogen fuel container mounted below a vehicle. The debris can, for example, be dislodged as a wheel passes over it. This impact level is used in a test from an EU standard for liquid fuel containers (i.e. gasoline or diesel), and subsequently applied to gaseous fuel containers. Impacts that can reach this energy level, would, for example, include a granite stone about 40 mm in diameter hitting at about 95 km/h, or a cube of steel about 22 mm on a side hitting at about 95 km/h. This level of impact is often considered as a means of evaluating protective coatings and is generally applied prior to chemical exposure testing.

4.3.3 488 J impact level

The 488 J impact level is based on the energy from dropping a man-portable cylinder weighing about 27,3 kg from a height of about 1,8 m. This is viewed as the highest combination of weight and height that can occur during transportation or installation by an individual. Such a drop can occur on any part of the cylinder.

The 488 J energy level reasonably represents energy of a similar cylinder falling off a loading dock or the bed of a transport vehicle. However, the energy level varies with the size of the cylinder. The impact is unlikely to occur axially on the end boss in such a fall. Accordingly, as cylinder size increases, the 488 J energy level is maintained on the end and is intended to be representative of other loads that can occur during handling, such as being hit by a forklift, or hitting an object while being transported by a forklift.

The 488 J energy level has been effective as a means of assuring impact resistance in the field based on safe responses to most incidents. There has also been some interest in testing to an impact energy level that is higher, but still less than the energy level of a high velocity impact.

4.3.4 1 200 J impact level

The 1 200 J impact level, by one account, addresses a stone of approximately 650 g kicked up by or falling off a vehicle travelling at 110 km/h in one direction, and impacting a cylinder going the opposite direction at 110 k/h. Such a stone would be approximately 80 mm to 90 mm in diameter, while a cube of steel with the same weight would be about 44 mm on a side. While this scenario is not as likely as the two energy levels discussed above, the energy level represents an impact that can occur in service.

Transported cylinders generally have some protection from road debris, including the truck bed and side walls.

4.3.5 Consequences

Some standards have adopted both the 488 J and 1 200 J impact levels, where passing the 488 J impact is mandatory, and a warning label is applied if the 1 200 J impact results are not successful.

Some possible consequences of low energy impacts, following subsequent pressure cycling, include crack growth, delamination, and liner leakage. While strength can be compromised by impacts, it does not necessarily result in rupture of the cylinder.

While cracks can grow during pressure cycling, the pressure cycling can also serve to blunt some of the stress concentration that results from the impact. In testing of cylinders with cut flaws, including deep cut flaws, a full lifetime of cycles was applied, and in some cases, the burst pressure was higher after cycling than without cycling[13]. However, the performance of the cylinder after an impact depends on factors such as the fibre type, fibre stress ratio, and construction. Performance dispersion within a production batch can also affect the evaluation of cylinder performance drop due to impacts.

An impact can also result in delamination within the wall. If the construction is exclusively continuous fibres, delamination between layers is not necessarily of consequence. In some cases, an intentional delamination between layers has been part of a design as a means of improving cyclic fatigue life. However, if localized reinforcements are included, such as dome caps or cloth inserts, and the localized reinforcements delaminate from the wound layers, the structural response of the laminate can be altered, and strength can be compromised.

An impact that causes cuts or broken fibres reduces the local stiffness of the laminate. This results in greater local deformation during pressure cycling, which results in lower fatigue life in a metal liner, and possibly leading to leakage of the cylinder contents.

4.4 Test concepts

The 30 J impact is generally applied in a test via a pendulum with a defined impacting mass and pivot arm length. An alternative can be a weight dropped from a given height. Caution is advised when using other methods to catch the impactor after the first impact, to avoid multiple impacts. The 488 J impact is often applied to transportable cylinders in the form of a drop test, but can also be conducted using a pendulum or dropped weight. The 1 200 J impact is also generally applied by a pendulum, but can also be applied using a dropped weight or by an impactor in a horizontal orientation that is powered by a pressurized gas.

The impact is based on equivalent energy, but consideration can be given to differences in momentum. Using the example of the 30 J impact, the momentum of the stone or steel cube would be the same, about 2,24 N·s. For a typical 30 J impact test, the mass is a steel pyramid of 15 kg, which would result in an impact velocity of about 1,41 m/s, and a momentum of 21,2 N·s, or about 10 times that of the possible field event. At this point, testing is based on energy, but it would be useful to understand how momentum influences results.

The cylinder is subject to pressure testing following the impact. Most current standards require pressure cycling. The upper cycle pressure generally is the working pressure. The number of cycles is generally reflective of the number of pressure cycles that occur between inspections, although several standards require the same number of cycles as the original cycle test. Some standards consider the test successful if the cycling is completed without a rupture of the cylinder. Other standards generally burst the cylinder after cycling, with a minimum pressure that can be, for example, 80 % of the original design burst pressure.

5 High energy impact (accidents)

5.1 General

High energy impact can occur due to accidents for a vehicle transporting a cylinder, or using it as a fuel container that can in some cases involve other vehicles. Examples of this include a single vehicle hitting a bridge or other structure, dropping a cylinder that is being transported, or a similar incident. A vehicle transporting a cylinder can be hit by another vehicle, such as an automobile, truck, or train, where it is possible for the cylinder to be hit directly or caused to be ejected from the transporting vehicle. A tube trailer, battery vehicle, or vehicle transporting a multiple element gas container (MEGC) can run off the road and roll over. Prevention of roll-overs or other road accidents can be considered when designing the tube trailer, battery vehicle, or MEGC. High energy impact can also result from misuse of the cylinder.

5.2 Visible indications

High energy impact generally gives visual evidence of the impact if the cylinder physically contacts another component. If there is visual evidence, it is likely to be rejected on this basis. Impact with a sharp or small diameter component is more likely to show evidence of impact. If there is a known impact, it is generally considered that the cylinder can be removed from service.

Impact with a flat component at high energy is also likely to show some indication of damage. In some cases, impact from a flat component results in resin crazing and a noticeable loss in composite properties, such as can be detected when the composite wall is tapped with a coin. It is also possible for an impact with a relatively flat component to cause reversal of curvature of a cylinder, fracturing the inner layers, without necessarily showing significant damage on the outer surface.

Cylinders have also been known to rupture during an impact event. At very high levels of energy, the difference between a rupture and a progressive failure releasing gas can be negligible. However, it is possible that a high energy impact by a relatively small structure will only result in a hole in the cylinder and a release of contained gas.

The characteristics of the impacting body, of how impact energy is distributed into the composite wall, and characteristics of the wall itself, affect results. Consideration of non-dimensional terms helps to understand how laminate damage can occur. Comparing items such as diameter of the impacting body to the wall thickness or cylinder diameter can show likelihood of penetration of the wall. Looking at the load over the affected area, compared with the transverse compressive strength or the shear strength of the laminate can show likelihood of penetration versus laminate crushing.

5.3 Design influence

Comparing the total energy of impact to reserve strength of the laminate, i.e. the difference between energy contained at burst pressure versus energy contained when impacted, can give insight as to whether the impact will result in simple damage, penetration, or rupture.

The location of a cylinder in a vehicle during an impact event has an effect on how much damage the cylinder receives. Energy is absorbed by either the vehicle or the frame, or both, during the event, which can offer some protection for the cylinder.

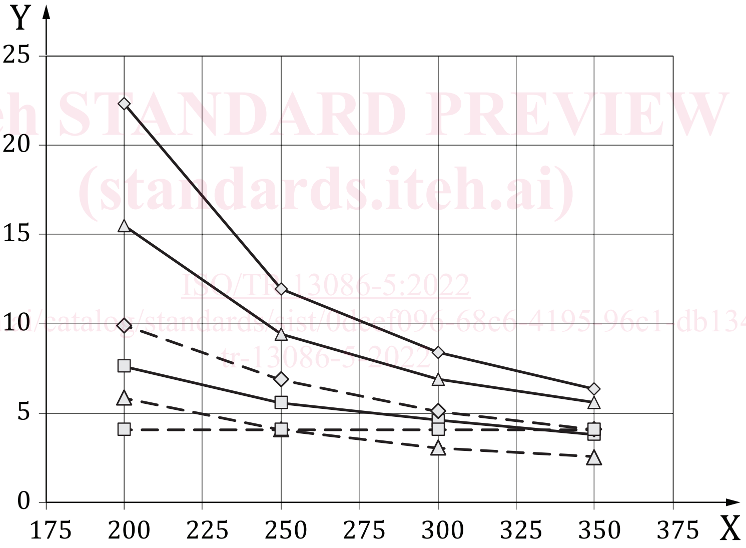
If the accident is such that the impact loading is only on a frame or container, and from the frame or container into the cylinder through the end bosses, it is possible that there is no visible damage, or even no damage, to the cylinder. In this case, AET or MAE can be required to assess if there is, in fact, any damage sustained by the cylinder in the accident. If it can be confirmed that there is no damage, the cylinder can safely remain in service.

The frame, container, or bundle structure is likely to absorb some of the energy through deflection or deformation, providing additional protection for the cylinders. A standard that addresses both cylinder design and frame design can offer information on design and testing that considers interaction of the cylinder and frame. The designer of the packaging would be aware of potential impact threats, and at a minimum conduct a failure modes and effects analysis (FMEA) to address possible concerns.

The pressure in the cylinder affects the level of damage incurred and the consequences. Pressure adds stress to the composite reinforcement, but it also stabilizes the wall, limiting deformation when impacted. Figure 1 shows cylinders with three diameters, each designed for four different service pressures, with a radial load in the cylinder applied at zero pressure and service pressure.

Figure 1 shows that deflection is greater for unpressurized cylinders than pressurized cylinders, as the pressure resists the impact load. Figure 1 also shows that larger diameter cylinders deflect less under load, for a determined stress level, given that the wall is thicker if the service pressure is the same. When pressurized after an impact at low pressure, the cylinder is more likely to have a lower burst pressure than a cylinder impacted at a higher pressure, given the greater deflection, and greater risk of damaged internal fibres, due to the impact loading.

The cylinder has an associated design margin of safety that allows some absorption of impact energy without rupture. The combination of pressurization and design margin limits risk of rupture. If there is a lower pressure in the cylinder, there is greater risk of damage, but the margin of safety is higher, and the contained energy is lower. Therefore, even with high damage risk, the safety risk is acceptable due to the reduced energy content. In any case, a cylinder with suspected damage would either be inspected or removed from service, or both.



Key

—◇— 254 mm, no pressure
—△— 508 mm, no pressure
—□— 1016 mm, no pressure
-◇- 254 mm, service pressure
-△- 508 mm, service pressure
-□- 1016 mm, service pressure

X service pressure (bar[1])
Y max displacement (mm)

1) 1 bar = 0,1 MPa = 105 Pa; 1 MPa = 1 N/mm

Figure 1 — Wall deflection under load versus diameter and contained pressure

The gas contents, i.e. whether it is compressed gas or liquified gas, have some influence on results of an accident. If the vehicle carrying the cylinder is moving, the contained mass affects the dynamic response of the cylinder and any framing. Depending on the level of the impact, the contained mass can also limit deformation of the wall.

The cylinder construction also affects the level of damage incurred. A thicker wall is generally regarded as more impact resistant. Lower strength materials result in a thicker wall. Glass fibre requires a higher stress ratio, or safety factor, than carbon fibre, so a cylinder with glass fibre reinforcement is generally regarded as more impact resistant.

The cylindrical section of the cylinder or tube is nominally the thickest part. The domes are generally thinner, with the thinnest part adjacent to the cylindrical section, and increasing in thickness moving towards the end boss.

Some cylinders are made using hybrid material construction, for example, using both carbon fibre and glass fibre. This gains the advantage of the improved stress rupture characteristics of the carbon fibre, and the advantage of a thicker wall by adding the glass fibre. Some hybrid construction intermixes the carbon and glass fibres while winding, while others use interspersed layers of carbon and glass. Still others use carbon fibre on the inside layers, and glass fibres on outer layers. Using fibres with different modulus of elasticity also has some benefits with structural dynamics during high energy impact.

The impact energy in one impact incident was calculated to be in the range of 80 000 J to 100 000 J. The energy level can be lower than this in some incidents, but it can be higher in others. As with low energy impacts, a consideration of different momentum levels would be of interest.

High energy impact testing is generally not included in qualification testing of cylinders and tubes. High energy impact is not common in the field, and the impact levels and means of application are varied. These factors make it difficult to develop a meaningful test. However, the designer can consider some impact testing outside the scope of the standards. This would serve to build knowledge on the impact energy threshold leading to cylinder performance drop and corresponding damage criteria, for the definition of adequate pre-fill (pass/fail) inspection criteria. Regardless of specific application, the maximum impact energy is likely the same for any cylinder that is used in transportation.

The current impact tests, including drop, low energy impact, and high velocity impact, are considered sufficient to address impact resistance of cylinders and tubes, such that a higher energy impact test is not necessary. This is supported by field experience, given that in addition to the low level of incidence, the consequences of these impact have not been such that a new qualification test is necessary.

Examples of known impact incidents are given in Clause 10.

6 Drop impact

6.1 General

Dropping of cylinders and tubes can occur during transportation, handling, and use. These drops can occur in virtually any orientation, horizontal, vertical, or at an angle, although the orientation can be somewhat controlled by the size and use of the cylinder.

A cylinder that is horizontal on a loading dock or transport truck can roll straight off the dock or truck bed, resulting in a horizontal drop. If it rolls off where one end extends off the dock or truck bed before the other, i.e. rolls off at an angle, then it is likely to be at an angle when it impacts the ground. A drop on the end of a cylinder is most likely when carried by hand.

6.2 Test scenarios

The height of the drop is derived from likely scenarios in service. A drop height of 1,8 m is generally used to reflect the maximum height of a loading dock or truck bed. This would also apply to a smaller cylinder carried by hand. As cylinder size increases, the likelihood of impacting from a drop on the end of the cylinder decreases. The vertical drop can be limited in energy or be replaced by a defined impact on the end of the cylinder or tube.

Similarly, larger tubes are not likely to be transported or moved without the use of either handling equipment or a cradle, or both, or support frame. In this case, the drop test can be replaced by an impact test.