TECHNICAL REPORT

ISO/TR 12391-1

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2001-12-15

Gas cylinders — Refillable seamless steel — Performance tests —

Part 1:
Philosophy, background and conclusions

Bouteilles à gaz — Rechargeables en acier sans soudure — Essais de performance —

Partie 1: Philosophie, historique et conclusions

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this part of ISO/TR 12391 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

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ISO/TR 12391-1 was prepared by Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

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ISO/TR 12391 consists of the following parts, under the general title *Gas cylinders — Refillable seamless steel — Performance tests*:

— *Part 1: Philosophy, background and conclusions*

— *Part 2: Fracture performance tests — Monotonic burst tests*

— *Part 3: Fracture performance tests — Cyclical burst tests*

— *Part 4: Flawed cylinder cycle test*

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Introduction

Gas cylinders as specified in ISO 9809-1 have been constructed of steel with a maximum tensile strength of less than 1 100 MPa. With the technical changes in steel-making using a two-stage process, referred to as ladle metallurgy or secondary refining, significant improvement in mechanical properties have been achieved. These improved mechanical properties provide the opportunity of producing gas cylinders with higher tensile strength, which achieve a lower ratio of steel to gas weight. The major concern in using steels of higher tensile strength with correspondingly higher design wall stress is safety throughout the life of the gas cylinder.

When ISO/TC 58/SC 3 began drafting ISO 9809-2, Working Group 14 was formed to study the need for additional controls for the manufacture of steel gas cylinders having a tensile strength greater than 1 100 MPa.

This part of ISO/TR 12391 presents the philosophy and background information developed by WG 14 to study the problems inherent with steel of higher tensile strength. It also states the conclusions of WG 14, which were included in ISO 9809-2.

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Gas cylinders — Refillable seamless steel — Performance tests —

Part 1: Philosophy, background and conclusions

1 Scope

This part of ISO/TR 12931 applies to seamless steel refillable cylinders of all sizes from 0,5 l up to and including 150 l water capacity produced of steel with tensile strength (R_m) greater than 1 100 MPa.

It can also be applied to cylinders produced of steels used at lower tensile strengths. In particular, it provides the technical rationale and background to guide future alterations of existing ISO standards or for developing advanced design standards.

2 References

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ISO 6406.1992, *Periodic inspection and testing of seamless steel gas cylinders*

ISO 9809-1:1999, *Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing — Part 1: Quenched and tempered steel cylinders with tensile strength less than 1 100 MPa*

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ISO 9809-2:2000, *Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing — Part 2: Quenched and tempered steel cylinders with tensile strength greater than or equal to 1 100 MPa*

3 Terms and definitions

For the purposes of this part of ISO/TR 12391, the following terms and definitions apply.

3.1
flawed cylinder burst test
test conducted on a finished gas cylinder having a deep prescribed flaw machined into the exterior sidewall and failed by internal pressurization

NOTE Pressurization can be hydraulic, applied either monotonically or cyclical. The flaw depth is in the range of 75 % of the cylindrical wall thickness.

3.2
flawed cylinder cycle test
test conducted on a finished gas cylinder having a shallow prescribed flaw machined into the exterior sidewall and failed by cyclical internal pressurization

NOTE Pressurization is normally hydraulic. The flaw depth is 10 % of the cylindrical wall thickness.

3.3
fracture performance
type of crack growth at the instant of through-wall failure, either by stable crack arrest or a running crack rupture, i.e. leak or fracture

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4 Symbols and abbreviations

4.1 Symbols

d = artificial flaw depth (mm),

D = nominal outside diameter of cylinder (mm),

l_o = length of artificial flaw (mm),

P_f = measured failure pressure (bar),

P_h = hydrostatic test pressure (bar),

P_s = calculated design working pressure (bar),

t_a = actual measured wall thickness at the location of the flaw (mm),

t_d = calculated minimum design wall thickness (mm),

R_e = actual measured value of yield strength (MPa),

R_m = actual measured value of tensile strength (MPa)

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4.2 Abbreviations

CVN = charpy V-notch impact test

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KIC = keyhole impact charpy

LBB = leak before break fracture performance

UTS = ultimate tensile strength

NOTE In ISO/TR 12391-2[1)] this term is to be defined as either “leak” or “fracture”.

5 Background

5.1 Participation

In 1989 ISO/TC 58/SC 3 formed a working group (WG 14) to study the potential need for controls in excess of those in ISO 9809-1 for the manufacture and testing of steel cylinders with tensile strengths greater than 1 100 MPa. Extensive technical considerations were essential to the development of an ISO standard for the production of a new generation of cylinders using higher tensile strengths to assure safe performance during their service life. A primary concern was the potential fatigue crack failure mechanism.

Seven member nations provided one or more technical members who had expertise in the technology of seamless steel gas cylinders. These countries and companies are listed in Table 1.

1) In preparation.

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Table 1 — List of participating countries

Country	Company	Status
Austria	J. Heiser	Producer
France	Air Liquide	User
	Valmont	Producer
Germany	Mannesmann	Producer
Japan	JISC	Regulator
	Sumikin Kiko	Producer
Sweden	AGA	User
United Kingdom	Chesterfield	Producer
USA	Norris Cylinder Co.	Producer
	Praxair	User
	Pressed Steel Tank Co.	Producer
	Taylor Wharton	Producer
	U.S. DOT	Regulator
	National Institute of Science & Technology	Technology

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5.2 Essential cylinder safety controls

The working group first studied and debated which physical attributes of cylinders would vary because of higher tensile strength and therefore affect critical safety performance of the cylinders. The need for additional manufacturing tests to control the envisioned critical attributes were then considered. Figure 1 is a flow chart of the analysis procedure.

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5.3 Safety controls

Each member nation presented a review of their existing control system for steels of various tensile strengths which were generally categorized by R_m as:

- below 950 Mpa;
- 950 to 1 100 Mpa;
- greater than 1 100 MPa.

Table 2 lists existing controls, which affect fracture performance, presented by Austria, France, Sweden, United Kingdom and USA in 1989. It was noted that these basic controls were similar in all nations and used traditional metallurgical factors. In 1989 only Austria and the USA had developed specific controls for steel with a tensile strength above 1 100 MPa.

In addition to the data given in Table 2, various experts put forth other considerations. Austria presented a procedure for predicting burst versus leak in a cycle/fatigue test. France presented the classic French burst test with a statistical time-history along with impact test data. Sweden stated that an increase in Charpy values would normally be required to assure adequate toughness at the increased strength level. The United Kingdom presented a concept of a hydro-burst test measuring total energy and presented a paper on that concept. Germany investigated the “Battelle Concept” and pointed out that those equations were only valid where the material exhibits ductile fracture behaviour, and the calculations are not applicable to brittle fracture or mixed fracture mode. The USA presented a procedure applied since 1985 for cylinders with tensile strength over 1 100 MPa, and test data from two manufacturers for the “Leak-before-break” (LBB) test concept on a pre-flawed cylinder.

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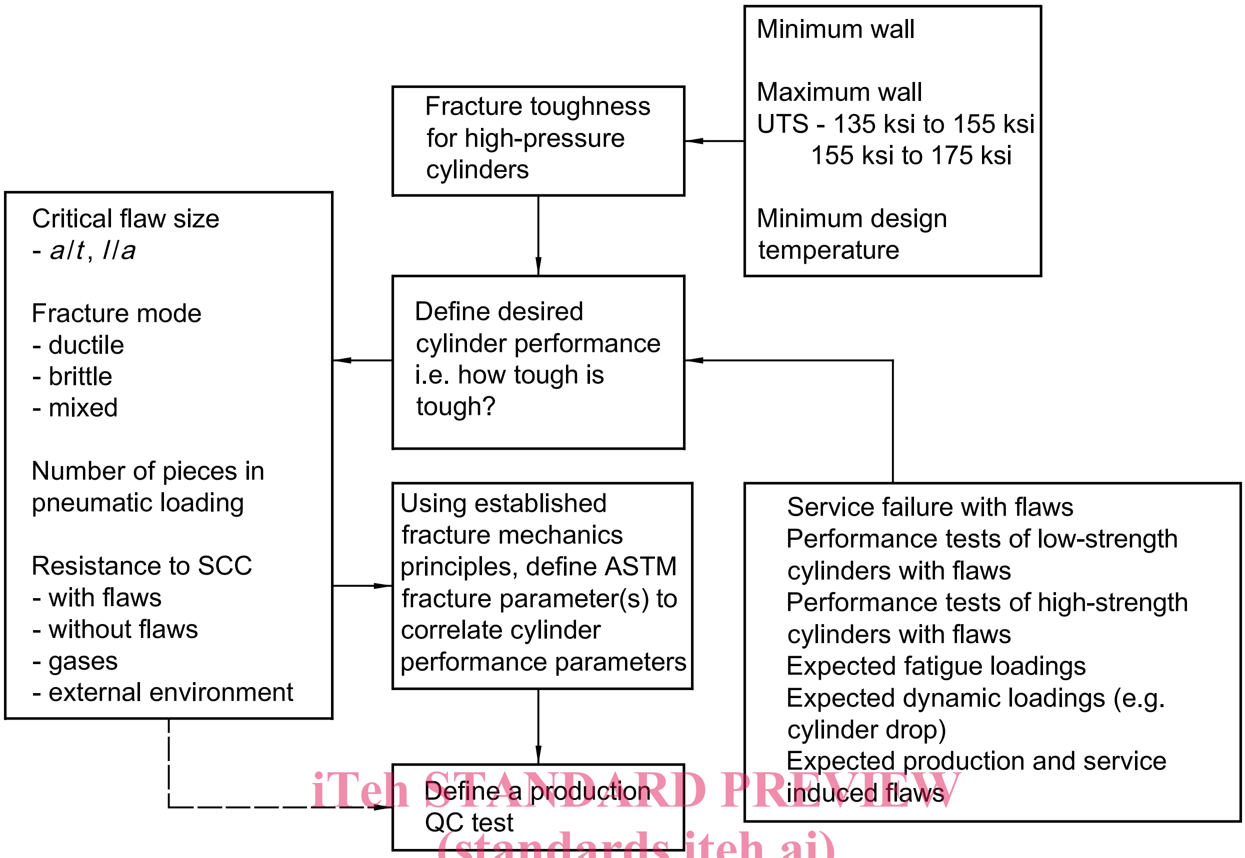

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Figure 1 — Flow chart of issues, objectives and approach

It was concluded that the only significant change in cylinder performance at strength levels above 1 100 MPa would be the potential reduction in toughness because of the substantial increases in tensile strength. Consequently, it was agreed that the critical control factor required was “To develop toughness acceptance level and test procedures for steel used in the construction of seamless cylinders with tensile strength above 1 100 MPa to assure a fracture safe performance”.

It was further agreed that current state-of-the-art control of fracture performance could be achieved by a flawed cylinder burst test and a Charpy V-notch test in the transverse direction at – 50 °C. An important consideration was to develop a test that tested the entire cylinder and not merely test samples taken from the cylinder wall.

At a later stage the work programme of WG 14 was extended to include a further test to control safe service performance and fatigue cycle life. As a consequence of this study, the flawed cylinder cycle test was adopted in ISO 9809-2.

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Table 2 — Fracture control — Current practices — 1989

Control factor	Member nation and strength level											
	Sweden			France	Austria		UK			USA		
R_m (N/mm^2)	< 950	950/1 100	> 1 100	All strengths	950/1 150	1 150	⩽ 1 030	⩽ 1 070	⩾ 1 100	⩽ 950 [a]	950/1 070	1 070/1 200
R_e/R_m	—	—	b	⩽ 0,9 for H_2 ⩽ 0,95 other	—	—	—	—	b	—	—	—
Elongation	14 %	14 % (ISO)	b	⩾ 16 % (5d gauge)	⩾ 14 % (ISO)	⩾ 12 % (ISO)	⩾ 14 % (ISO)	⩾ 14%	b	⩾ 20 % 2 in × 1,5 in gauge	⩾ 16 % 2 in × 1,5 in gauge	⩾ 12 % 2 in × 1,5 in gauge
Burst	P_b/P_h = NR	P_b/P_h ⩾ 1,6	b	P_b/P_h ⩾ 1,67	In accordance with ISO P_b = –	In accordance with ISO P_b = –	—	In accordance with ISO P_b = –	b	c	—	Flawed burst
Burst fracture appearance	NR	NR	b	Propagation into thicker section ⩽ 1,2 t	No limit on propagation length	No limit on propagation length	—	—	b	—	—	—
L/temperature	50/–50 °C	50/–50 °C	b	50/–20 °C	60/–20 °C	50/–20 °C	—	40/–20 °C	b	d	58/–18 °C	—
CVN (J/cm^2) T/temperature	—	—	b	—	For t > 5mm 25/–20 °C	25/–20 °C	—	—	b	—	—	44/– 18 °C
KIC	—	—	b CVN <-->KIC	—	—	—	—	—	b	—	—	⩾ 85 Ksi

a USA limited R_m to 930 N/mm^2 for hydrogen and embrittling gases.

b No specific control.

c Burst test not required as production test; but US DOT requires maximum of 2,5 P_s (1,5 P_h) for standard 3A and 3AA.

d CVN not required as production test, however industry control limits are 51 J/cm^2, L at – 50 °C and average 102 J/cm^2, L at – 50 °C.

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