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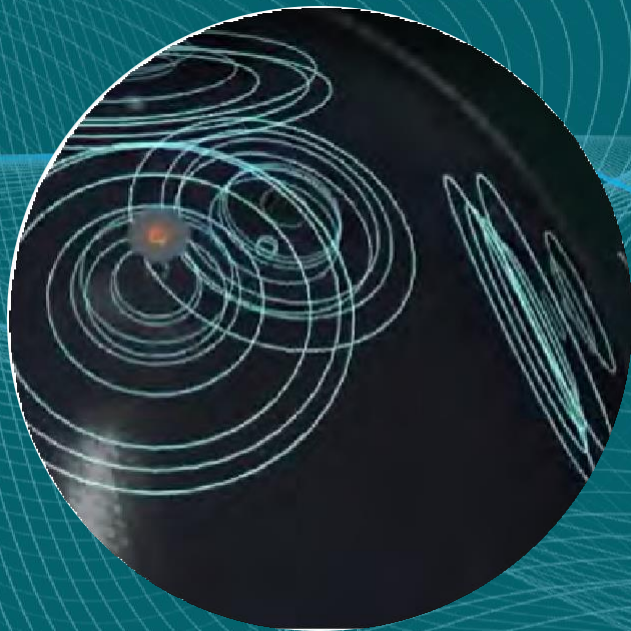
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(MAE) Modal Acoustic Emissions Testing



Hexagon Digital Wave, as the industry leader in Modal Acoustic Emission (MAE) testing of composite pressure vessel, has been at the forefront of advancing the technology in SCBA cylinder structural analysis.

Unlike Hydrostatic testing, MAE testing is sensitive enough to detect structural flaws that lead to composite failures. With Transport Canada equivalency certificate # SU13583 and Special Permit - 16320, reissued by DOT, adding an additional 15 years of service life from date of manufacturing.



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Source: Hexagon Composites ASA
June 24, 2022 02:00 ET

Hexagon Digital Wave's proprietary Modal Acoustic Emission technology approved for use in Canada

June 24, 2022 - Hexagon Digital Wave, a business of Hexagon Composites, has received an equivalency certificate from Transport Canada (TC) authorizing the use of its Modal Acoustic Emission (MAE) technology in continued service life requalification of cylinders used in firefighting applications. This equivalency certificate represents entry into Canada, a new market for Hexagon Digital Wave.

With an initial service life of 15 years, for cylinders to remain in service for a maximum service life of 30 years, the cylinders need to be requalified once every 5 years using the Modal Acoustic Emission requalification process.

Modal Acoustic Emission provides first responders with the confidence in knowing their cylinders have been requalified with the safest TC and DOT (Department of Transport in the US) approved technology. By continuing the service life of cylinders, Fire Departments can refocus their time, energy, and budgets on other key functions of firefighting that need continual attention," says Melissa Holler, President, Hexagon Digital Wave. "Continued service life requalification of the cylinders is the first advancement in technology brought to the North American Fire Service that doesn't come with a significant cost attached."

Joint research project

The certification is the direct result of a joint [research project](#) between Transport Canada and Hexagon Digital Wave that took place in 2020 to evaluate end of life performance and requalification methods for TC-3CCM cylinder used in Fire Fighting applications. Cylinders approaching 15 years of service life were collected from Canadian Fire departments to be part of the study to evaluate end of life burst strength, ambient cycle life, notch tolerance, impact tolerance, environmental exposure, and improvement of liner fatigue life. Furthermore, the study evaluated the efficacy of the 3 potential requalification methods (Hydrostatic testing, Modal Acoustic Emission, and feature based Acoustic Emission) for TC-3CCM cylinders.

The study concluded that all cylinders tested at or approaching the end of their service life possessed:

- residual burst strength greater than that required at time of manufacture.
- residual cycle life compared to an additional 15 years of service.
- acceptable notch and impact tolerance.
- residual cycle life with respect to extreme temperature environmental cycling.

The study found Modal Acoustic Emission to be the most effective method relative to identifying structurally compromised cylinders.

With the issuance of this TC-SU 13583 certification, Transport Canada becomes the second regulatory agency authority with high pressure compressed gas cylinder oversight to acknowledge and approve the benefits and safety provided by Modal Acoustic Emission.

Driving energy transformation

By continuing the service life of cylinders, raw material and energy consumption is reduced and landfill waste eliminated, truly achieving Hexagon's vision of Clean Air Everywhere. To date, Modal Acoustic Emission has helped avoid 235 metric tons of landfill waste globally.

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About Hexagon Digital Wave

Hexagon Digital Wave, a business of Hexagon Composites ASA, is a manufacturer of Ultrasonic Examination (UE) cylinder testing equipment, Modal Acoustic Emission (MAE) testing equipment and a provider of associated inspection services. With applications worldwide, Hexagon Digital Wave serves government entities, academic institutes, and private clients in the compressed gas and pressure vessel industries.

About Hexagon Composites ASA

Hexagon delivers safe and innovative solutions for a cleaner energy future. Our solutions enable storage, transportation, and conversion to clean energy in a wide range of mobility, industrial and consumer applications.

Learn more at www.hexagongroup.com and follow @HexagonASA on Twitter and LinkedIn.



Alberta Fire Chiefs Association

Professionals Serving Professionals



September 12, 2022

Alberta Fire Chiefs Association in Conjunction with Hexagon Digital Wave shares this announcement of revolutionary technology to create the potential to double the life span of carbon composite cylinders.

Transport Canada has recently issued an Equivalency Certificate (basically an exemption to the TDG Regulations) that allows certain carbon composite cylinders with a seamless aluminum liner to be used past their 15-year service life provided that the cylinders pass a specific testing protocol. Hexagon Digital Wave, LLC has received this certification authorizing the use of its Modal Acoustic Emission (MAE) technology to conduct this specific testing.

The Alberta Fire Chiefs Association along with the Canadian Association of Fire Chiefs – National Advisory Council, played a large part in advocating Transport Canada in this tremendous news for all fire services in this country. The potential to double the life span of carbon composite cylinders through this process will have meaningful budgetary and positive environmental impacts.

[Hexagon Digital Wave's proprietary Modal Acoustic Emission technology approved for use in Canada](#)

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Equivalency Certificate (Approval issued by the competent authority of Canada)

Certificate Number: SU 13583
Template Number: N/A
Certificate Holder: Hexagon Digital Wave, LLC
Mode of Transport: Road, Rail, Marine, Air
Effective Date: June 13, 2022
Expiry Date: June 30, 2027

LEGEND

For the purposes of this equivalency certificate, documents referred to by an abbreviation have the following meaning:

TDG Act: *Transportation of Dangerous Goods Act, 1992*

TDG Regulations: *Transportation of Dangerous Goods Regulations*

CGA C-6.2-2019: CGA C-6.2-2019, "Standard for Visual Inspection and Requalification of Fiber Reinforced High Pressure Cylinders", eighth edition, published by the Compressed Gas Association Inc. (CGA)

CSA B339-18: CSA Standard B339-18, "Cylinders, spheres, and tubes for the transportation of dangerous goods", published by the Canadian Standards Association (CSA), June 2018

CSA B340-18: CSA Standard B340-18, "Selection and use of cylinders, spheres, tubes, and other containers for the transportation of dangerous goods, Class 2", published by the Canadian Standards Association (CSA), June 2018

ISO 11119-2:2020: 11119-2:2020, "Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tubes — Part 2: Fully wrapped fibre reinforced

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composite gas cylinders and tubes up to 450 L with load-sharing metal liners", published by the International Standards Organization (ISO), November 2020

CAN/CGSB-48.9712-2014 / (ISO 9712:2012, IDT): CAN/CGSB-48.9712-2014 / (ISO 9712:2012, IDT), "*Non-destructive Testing – Qualification and Certification of Personnel*", dated 2014

ANSI/ASNT CP-189-2011: ANSI/ASNT CP-189-2011, "*ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel*", dated 2011

SNT-TC-1A-2016: SNT-TC-1A-2016, "*Recommended Practice No. SNT-TC-1A, Personnel Qualification and Certification in Nondestructive Testing*", dated 2016

NOTES

Note 1: Subsection 31(4) of the *TDG Act* stipulates that any non-compliance with the conditions of this equivalency certificate will result in the provisions of the *TDG Act* and *TDG Regulations* to apply as though this equivalency certificate did not exist.

Note 2: This equivalency certificate provides no regulatory relief other than specifically stated herein. Therefore, all other requirements of the *TDG Act* and the *TDG Regulations* apply.

PURPOSE

(The following is for information purposes only and is not part of the certificate.)

The equivalency certificate holder has demonstrated that the use of TC-3CCM specification cylinders can be extended past the 15-year service life limitation, if they are successfully tested and requalified by the modal acoustic emission test method described in Appendix A of this equivalency certificate and subjected to the conditions listed in this equivalency certificate. The cylinders can be used up to a total life of 30 years with a level of safety at least equivalent to those cylinders currently permitted by the *TDG Regulations*.

CONDITIONS

1. This equivalency certificate authorizes **Hexagon Digital Wave, LLC** to display the marks prescribed in respect of cylinder requalification in a manner that does not comply with:

- section 6 of the *TDG Act*, and

authorizes any person to handle, offer for transport, or transport, by road or railway vehicle, by aircraft or by vessel, dangerous goods that are:

UN Number	Shipping Name and Description	Class	Packing Group
UN1002	Air, compressed (breathing air containing up to 23.5% oxygen, by volume)	2.2	N/A

in cylinders in a manner that does not comply with the following requirements:

- subsection 5.1.1(2) of the *TDG Regulations*,
- section 5.2 of the *TDG Regulations*,
- subparagraphs 5.10(1)(a)(ii), 5.10(1)(b)(iii), 5.10(1)(c)(ii) and 5.10(1)(d)(iii) of the *TDG Regulations*, but only as it relates to clauses 4.6.2(d) and 5.1.4 of *CSA B340-18*,

if the following conditions are met:

- (a) Each cylinder has been manufactured in accordance with:
 - (i) specification TC-3CCM set out in the edition of *CSA B339* in force under the *TDG Regulations* at the time of manufacture,
 - (ii) one of the following equivalency certificates issued by the Transportation of Dangerous Goods Directorate of Transport Canada: SU 5134, SU 5141 or SU 5303;
- (b) Despite Clause 24.2.7 of *CSA B339-18*, cylinders may be considered for an extended service life not exceeding 30 years after the original manufacturing test date of the cylinder and shall be condemned at the termination of the 30-year period following the date of the original test marked on the cylinder;

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(Approval issued by the competent authority of Canada)

- (c) For each cylinder considered for extended service life, requalification is performed by **Hexagon Digital Wave, LLC**, hereinafter referred to as the equivalency certificate holder, and is performed in accordance with the documentation filed by the equivalency certificate holder with the Regulatory Frameworks and International Engagement Branch, Transportation of Dangerous Goods Directorate, Transport Canada and in accordance with Appendix A to this equivalency certificate;
- (d) Cylinders passing the requalification and marked with “**TC-SU 13583**” are authorized for an additional 5 years of service, despite clause 24.2.7 of *CSA B339-18* and clause 4.6.2 (d) of *CSA B340-18*. Cylinders with the TC-SU 13583 marking shall be successfully requalified once every 5 years using the requalification method as per condition (c) of this equivalency certificate in order to remain in service for a maximum service life of 30 years from the date of manufacture;
- (e) Each cylinder that has passed the requalification described in this equivalency certificate for extended service life shall be marked “**TC-SU 13583**”. The original TC-SU or TC-3CCM specification shall remain visible. The marking shall be applied on a tamper resistant label securely affixed to the shoulder of the cylinder and protected with a damage resistant cover. Stamping of any part of the cylinder is prohibited;
- (f) Each cylinder requalified according to this equivalency certificate shall be marked in accordance with Clause 24.6 of *CSA B339-18*. The procedure symbol shall be “**MAE**”. The marking shall be applied on a tamper resistant label securely affixed to the shoulder of the cylinder and protected with a damage resistant cover. Stamping of any part of the cylinder is prohibited;

When a cylinder is required to be condemned, a label with the word “**CONDEMNED**” overcoated with epoxy shall be securely affixed to the cylinder;

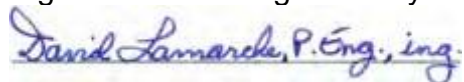
- (g) Each cylinder covered by the terms of this equivalency certificate must have a prominent warning label on the external surface of the cylinder that indicates “**The cylinder must be externally inspected per CGA C-6.2 prior to every fill.**”;
- (h) Cylinders with evidence of having been subjected to the action of fire shall not be requalified under this equivalency certificate nor returned to service;
- (i) All cylinders marked with TC-SU 13583 are subject to the in-service life extension revalidation plan which must be submitted to Transport Canada within 12 months of the issuance of this equivalency certificate and include:
 - (i) A detailed procedure for obtaining the TC-3CCM or TC-SU 5134, SU 5141 or SU 5303 from the field and design qualification testing of each design type,

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- (ii) A procedure for the random selection of a minimum of 5 cylinders which have been in service for 18, 21, 24 and 27 years,
 - (iii) All randomly selected cylinders from the field must be tested in accordance with Sections 8.5.4, 8.5.5, 8.5.7 and 8.5.8 of *ISO 11119-2:2020*. Acceptance criteria must be as defined in *ISO 11119-2*; and
 - (iv) The complete MAE test report, including the original test data, must be submitted to Transport Canada within 30 days of completion of the test. Failure to meet the acceptance criteria in this equivalency certificate may result in the design being restricted to a maximum life of 15 years;
- (j) The equivalency certificate holder reports to the Regulatory Frameworks and International Engagement Branch, Transportation of Dangerous Goods Directorate, Transport Canada:
- (i) the name and qualifications of each Senior Review Technologist (SRT), qualified tester, and qualified operator, as defined in Appendix A to this equivalency certificate,
 - (ii) once per 12 calendar months, a summary of the test results at each facility, including the total number of cylinders tested under this equivalency certificate grouped by type, size and age. The summary must include the number of cylinders accepted, rejected or condemned. For any rejected or condemned cylinders, the defect causing the rejection/condemnation must be fully characterized and profiled (ie. Cuts, abrasions, impacts, fiber failures, chemical damage, heat damage, etc.) and the specific size of the defect be determined (i.e. length, depth, width, etc.). The cylinders that were condemned at visual inspection prior to modal acoustic emission testing must also be included in the report.
2. This equivalency certificate serves as the registration of **Hexagon Digital Wave, LLC** in accordance with Clause 25.3 of *CSA B339-18*, to requalify cylinders as specified herein. **Hexagon Digital Wave, LLC**'s registered mark is:

“628”

Signature of Issuing Authority



David Lamarche, P. Eng., ing.
Chief, Approvals and Special Regulatory Projects

Appendix A

1. REQUALIFICATION METHOD

Each cylinder shall be visually inspected internally and externally and be subjected to modal acoustic emission (MAE) examination in accordance with the following.

2. VISUAL INSPECTION

Prior to MAE examination, the cylinder shall be visually inspected externally and internally in accordance with *CGA C-6.2-2019* and with Hexagon Digital Wave, LLC's documentation entitled "Internal and External Visual Inspection of Fiber Reinforced High Pressure Cylinders" dated January 10, 2019 on file with the Transportation of Dangerous Goods Directorate.

3. MODAL ACOUSTIC EMISSION TEST

- 3.1 The entire cylinder under test shall be tested using equipment, procedures and rejection criteria in accordance with the United States Department of Transportation (U.S. DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) technical report "Modal acoustic emission (MAE) Examination Specification for Requalification of Composite Overwrapped Pressure Vessels (Cylinders and tubes)", dated May 3, 2018, and supporting documents on file with the Transportation of Dangerous Goods Directorate.
- 3.2 For the pressurization of the cylinders during the modal acoustic emission testing as per 3.1, if a cylinder is dual marked with DOT-CFFC and TC-3CCM or TC-SU marking, the test pressure shall be the higher of the DOT-CFFC service pressure times $5/3$ and the TC-3CCM or TC-SU service pressure times 1.5. For cylinders marked only with TC-3CCM or TC-SU marking, the test pressure shall be 1.5 times the marked service pressure.

4. MODAL ACOUSTIC EMISSION EXAMINATION PERSONNEL

- 4.1 Each person who performs testing or who evaluates or certifies results shall meet the requirements in this equivalency certificate.
- 4.2 A Project Manager is a senior manager of Hexagon Digital Wave, LLC responsible for compliance with the *TDG Regulations* including this equivalency certificate. Additionally, the Project Manager shall ensure that each operator and Senior Review Technologist (SRT) maintain the required certifications described herein.
- 4.3 The personnel responsible for performing modal acoustic emission testing in accordance with this equivalency certificate shall be qualified to an appropriate level (Level I, Level II or Level III) in modal acoustic emission (MAE) testing in accordance with the *CAN/CGSB-48.9712-2014 / (ISO 9712:2012, IDT)*,

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ANSI/ASNT CP-189-2011, or *SNT-TC-1A-2016* depending on the assigned responsibility as described below:

- (a) System start up, system calibration, review, and certification of the test results shall be performed by a SRT or by a qualified tester when written acceptance and rejection criteria has been provided by a SRT. Based upon the written criteria, the qualified tester may authorize cylinders that pass the requalification to be marked in accordance with this equivalency certificate;
 - (b) A person with Level I certification may perform system start up, check calibration and perform MAE under the direct guidance and supervision of a SRT or a qualified tester, either of whom shall be physically present at the test site to be able to observe examinations conducted under this equivalency certificate.
- 4.4 A SRT shall be a person who provides written MAE procedure, supervisory training, examinations (Level I and II), and technical guidance to operators, reviews and verifies the examination results. An SRT shall have a thorough understanding of the *TDG Regulations* pertaining to the manufacture and requalification of cylinders that are authorized under this equivalency certificate and shall possess:
- (a) a Level III certification in accordance with *CAN/CGSB-48.9712-2014 / (ISO 9712:2012, IDT)*, *ANSI/ASNT CP-189-2011*, or *SNT-TC-1A-2016* in modal acoustic emission examination;
 - (b) a Professional Engineer (PE) License with a documented experience for a minimum of 2 years in Non-Destructive Evaluation (NDE) of pressure vessels or pipelines using the modal acoustic examination technique; or
 - (c) a PhD degree in a discipline of engineering or physics with documented evidence of experience in non-destructive examination (NDE) of pressure vessels or pipelines using the modal acoustic examination technique or research/thesis work and authoring/co-authoring of technical papers published, in recognized technical journals, in the fields of modal acoustic examination methods.
- 4.5 A qualified tester shall be certified to Level II in accordance with *CAN/CGSB-48.9712-2014 / (ISO 9712:2012, IDT)*, *ANSI/ASNT CP-189-2011*, or *SNT-TC-1A-2016*, and shall be a person who has at least:
- (a) two years continuous experience of a technical nature involving cylinders or tubes;
 - (b) 40 hours of training or instruction in modal acoustic examination of cylinders or other pressure vessels; and

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- (c) 40 hours of experience in modal acoustic examination of cylinders or tubes under the supervision of an SRT.
- 4.6 The MAE operator shall be capable of examining waveforms event by event and the waveforms for each event shall precisely correspond with the pressure and time data during the test.
- 4.7 The SRT shall prepare and submit the records required in section 5 of Appendix A of this equivalency certificate and annually verify that the MAE program is being operated in accordance with the requirements of the equivalency certificate.
- 4.8 The most recent copies of certification (e.g. ASNT Level or PE license) shall be available for inspection at each requalification facility.

5. RECORDS

A record shall be prepared documenting the examination conditions and requalification results including:

- (a) a reference to this equivalency certificate number;
- (b) the name of cylinder owner or operator;
- (c) the name of the qualified SRT who performed or supervised the modal acoustic examination, as well as the MAE operator's name and certification level and the identification of the persons who performed the external visual inspection, as applicable;
- (d) the cylinder serial number;
- (e) the name or registered mark of the manufacturer;
- (f) the MAE test pressure;
- (g) the sensor configuration;
- (h) the pressurization medium;
- (i) the specification or equivalency certificate to which the cylinder was manufactured and its marked service pressure;
- (j) the cylinder water capacity;
- (k) the event energies exceeding the fiber tow fracture failure criteria (if applicable);
- (l) the event energies exceeding the fretting emission energy allowable criteria (if applicable);
- (m) the background energy oscillation pressure (if applicable);
- (n) the background energy rise (if applicable);
- (o) the requalification facility location;
- (p) the requalification date;
- (q) the external and internal visual inspection results (pass/fail);
- (r) the MAE requalification results (pass/fail);
- (s) the previous examination date and previous test pressure;
- (t) a record of system calibration before and after cylinder acoustic examination.

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(The following is for information purposes only and is not part of the certificate.)

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SH - Road, SR - Rail, SA - Air, SM - Marine SU - More than one Mode of Transport Ren - Renewal	

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Research Summary – Evaluation of End of Life Performance and Requalification Methods for TC-3CCM Cylinders

Transportation of Dangerous Goods | Scientific Research Division

SUMMARY

This study found that TC-3CCM cylinders at or approaching the end of their 15-year service life possessed:

- Residual burst strength greater than that required at time of manufacture (Figure 1);
- Residual cycle life comparable to an additional 15 years of service;
- Acceptable notch and impact tolerance; and
- Residual cycle life with respect to high and low temperature environmental cycle testing.

The study also compared the efficacy of the three (3) requalification methods (hydrostatic, Modal Acoustic Emission (MAE), and Acoustic Emission (AE) testing for inspection of Type 3 composite cylinders.



Figure 1 – Burst testing

BACKGROUND

Research on the potential for continued service life of TC-3CCM (DOT-CFFC) cylinders used in first responder applications was initiated by the U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) in 2014. Three (3) concurrent studies evaluated end of life burst strength, ambient cycle life, notch tolerance, impact tolerance, environmental exposure, and improvement of liner fatigue life in Type 3 cylinders (1) (2) (3). Furthermore, MAE testing was validated as effective in assessing composite cylinder integrity and as possessing at least an

equivalent level of safety as the method currently required by regulations. Special permits have been issued in the U.S. for continued life service based on the studies done thus far. As of 2020, roughly 10,000 cylinders have had life extension approved after undergoing MAE inspection.

OBJECTIVES

The aims of this study were twofold:

- Evaluate the physical performance of cylinders which had experienced near 15 years of field service (“end of life” cylinders); and
- Evaluate the efficacy of the hydrostatic test method, MAE test method, and the AE test method.

METHODS

Cylinders at or near the end of a 15 year service life were donated from Canadian fire departments and grouped by design variants (i.e., service pressure and air volume). Three (3) design variants covering design types most susceptible to liner fatigue, impact damage, composite degradation, and commercial availability were selected for consideration in this study. Table 1 identifies all physical test methods, governing standards which dictated test protocols, and acceptance criteria for each of the physical test methods.

Table 1 – Physical test methods

Physical Test	Governing Standard	Acceptance Criteria
Burst Test	CSA B339 §9.11.4	$P_B \geq 3.4 P_S$
Ambient Cycle Test	ISO 11119.2 §8.5.5	$N = 7500$ cycles to P_{MAX}
Notch Tolerance Test	ISO 11119.2 §8.5.7	<u>Fatigue Replicate</u> $N > 1000$ cycles to P_S w/o leak $N = 5000$ cycles w/o catastrophic failure
		<u>Burst Replicate</u> $P_B \geq 1.33 P_H$
Impact Tolerance Test	CSA B339 §9.13.8	<u>Fatigue Replicate</u> $N > 1000$ cycles to P_S
		<u>Burst Replicate</u> $P_B \geq 3.06 P_S$
Environmental Cycle Test	CSA B339 §9.13.4	$N = 5000$ cycles to P_S at 60 °C and $\geq 95\%$ RH $N = 5000$ cycles to P_S at -50 °C $P_B \geq 3.06 P_S$

(P_B : burst pressure; P_S : service pressure, P_{MAX} : maximum developed pressure; P_H : test pressure; RH: relative humidity)

In addition to cylinder physical performance, the efficacy of three (3) current or proposed standardized test methods was simultaneously evaluated in assessing cylinder integrity (Figure 2): hydrostatic (CSA B339 §24), MAE (DOT-SP 16320 and ISO/TS 19016), and AE (ISO/CD 23876) testing.



Figure 2 – Requalification test apparatus

RESULTS

Cylinders from all three (3) design variants at the end of a 15 year service life possessed residual burst strength greater than the 'at time of manufacture' burst strength required by CSA B339 §9.13.5 for TC-3CCM cylinders.

Cylinders from all three (3) design variants at the end of a 15 year service life completed an additional 15 years of service per ISO 11119.2 §8.5.5 without failing, either catastrophically or via liner leakage.

Cylinders from all three (3) design variants at the end of a 15 year service life exceeded the 'at time of manufacture' performance requirements of the notch tolerance testing specified in ISO 11119.2 §8.5.7.

Cylinders from all three (3) design variants at the end of a 15 year service life exceeded the 'at time of manufacture' performance requirements of the impact tolerance testing specified in CSA B339 §9.13.8.

Cylinders from all three (3) design variants at the end of a 15 year service life exceeded the 'at time of manufacture' performance requirements of the environmental cycle testing specified in CSA B339 §9.13.4(b).

Table 2 summarizes the efficacy of the three (3) considered requalification test methods. A false positive means a test result showed that a cylinder would fail a burst test when it still had adequate strength to meet the burst test requirement. In this situation, a cylinder might be rejected prematurely, leading to greater cost for cylinder users. A false negative means that a test result showed that a cylinder would meet the burst test requirement even though it later did not,

and should have been rejected. This second case is of greater concern, as a false negative leads to a potentially unsafe situation.

Table 2 – Requalification method outcomes

Test Method	False Positive [%]	False Negative [%]
Hydrostatic	1.3	3.8
MAE	3.8	1.3
AE (N _s = 500)	24.4	1.3

(N_s: number of signals)

CONCLUSIONS

All tested TC-3CCM cylinders at or approaching the end of their service life possessed residual burst strength greater than that required at time of manufacture, residual cycle life comparable to an additional 15 years of service, acceptable notch and impact tolerance, and residual cycle life with respect to extreme temperature environmental cycling.

In this study, it was found the hydrostatic test method had the lowest false positive rate (1.3%), but the highest false negative rate (3.8%) as it did not correctly reject any cylinder with compromised structural performance. The MAE test method was found to have a higher false positive rate than hydrostatic testing, (3.8%), but a lower false negative rate (1.3%). AE acceptance criteria were tailored to achieve a false negative rate of 1.3% but resulted in a false positive rate of 24.4%. Attempts to reduce the false positive rate for the AE test method by increasing the acceptance



criterion resulted in an increase of the false negative rate.

FUTURE ACTION

This project has concluded, and further work is not currently planned by the Scientific Research division.

REFERENCES

1. **Burks, Brian, Ziola, Steve and Gorman, Michael.** *Use of Modal Acoustic Emission (MAE) for life extension of civilian self-contained breathing apparatus (SCBA) DOT-CFFC cylinders.* Washington, D.C. : US DOT/PHMSA, 2014.
2. —. *Environmental Exposure Effects on DOT-CFFC Cylinders with Modal Acoustic Emission Examination.* Washington D.C. : US Department of Transportation, 2015.
3. —. *Fatigue life improvement of DOT-CFFC composite cylinders.* Washington D.C. : US Department of Transportation, 2015.

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This work was done with Hexagon Digital Wave, LLC, and TDG acknowledges the contributions of Dr. Brian Burks and his team Zack Prather, Tyler Perkins, Sal Passalacqua, Cody Estes, and Shannon Austgen.

CONTACT

To obtain a copy of the report, please contact us:

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KEYWORDS

Continued Service Life, composite pressure cylinder, TC-3CCM, DOT-CFFC, extension of life (EOL), Modal Acoustic Emission (MAE), Acoustic Emission (AE), hydrostatic testing, requalification



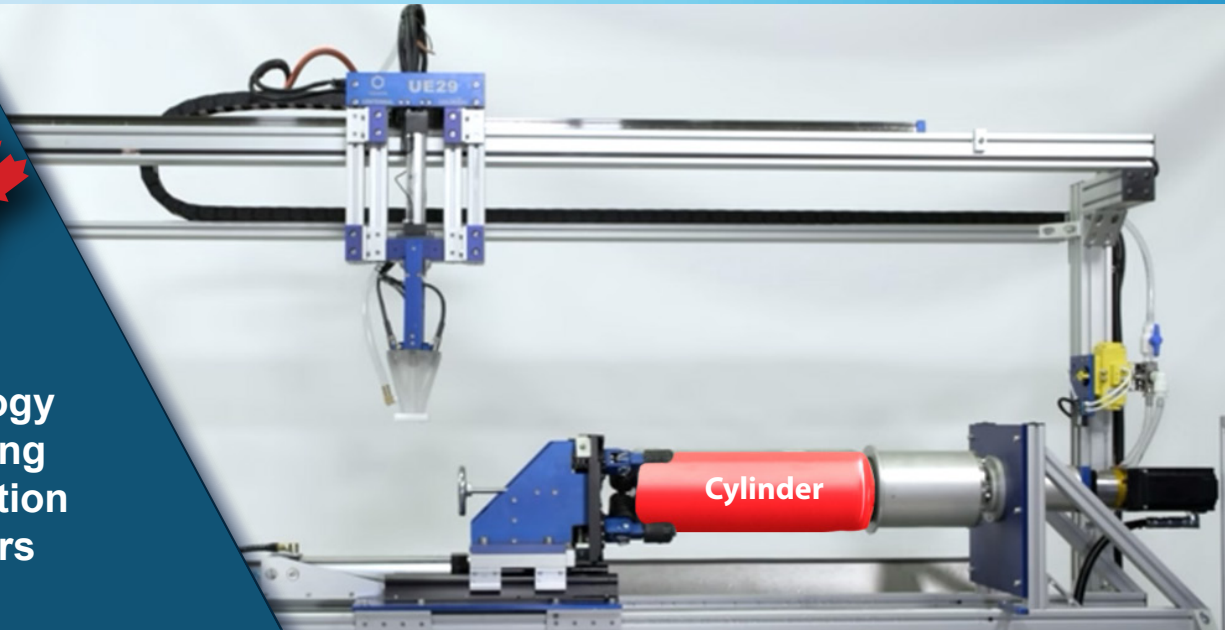
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