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	Fatigue Replicate N > 1000 cycles to P_S w/o leak N = 5000 cycles w/o catastrophic failure
		Burst Replicate $P_B \geq 1.33\ P_H$
Impact Tolerance Test	CSA B339 §9.13.8	Fatigue Replicate N > 1000 cycles to P_S
		Burst Replicate $P_B \geq 3.06\ P_S$
Environmental Cycle Test	CSA B339 §9.13.4	N = 5000 cycles to P_S at 60 °C and ≥ 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.

ISBN: 978-0-660-36818-4

Catalogue Number: T86-66/2020E-PDF

ACKNOWLEDGEMENTS

The cylinder donations of Moncton Fire Department, Uxbridge Fire Service, Whitby Fire and Emergency Services, Canadian Armed Forces and 5th Canadian Division Support Base Gagetown, Firefighters Without Borders, Vaughan Fire and Rescue Service, Ottawa Fire Services, and Service de protection contre l'incendie de la Ville de Quebec are gratefully acknowledged.

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:

TDG Scientific Research Division
TC.TDGScientificResearch-RecherchescientifiqueTMD.TC@tc.gc.ca

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