



RECOMMENDATIONS FOR AVOIDANCE OF SUSTAINED LOAD CRACKING OF ALUMINIUM ALLOY CYINDERS

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Prepared by WG-2 Gas cylinders and pressure vessels
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Amendments from 57/18

Section	Change
6.3.1.1	Add a Note how to reduce the tensile stress

1 Introduction

This publication was prepared at the end of the 1990s and revised in 2004, 2011, 2018 and then, in 2024. During the 2024 revision, the following information was added:

- Note in chapter 6.3 how the tensile stress can be reduced

This edition includes updated standards references.

2 Scope and purpose

This publication gives recommendations for the purchase of new aluminium alloy cylinders and the manner of treating those already in service.

The principal aim of this publication is to avoid and/or detect sustained load cracking (SLC) of cylinders manufactured from aluminium alloys 6351 and 6082, see Appendix 1, though relevant features may be used for other aluminium alloys as appropriate. Previously documented stress-corrosion cracking aspects associated with other aluminium alloy cylinder materials are not the subject of this publication, nor are the ageing aspects of a number of heat treatable aluminium alloy cylinders. To date, the vast majority of the cracking phenomenon has been observed in the neck/shoulder areas of the cylinders though some cracks in the cylindrical part have also been recently reported.

3 Definitions

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

4 Background

Gas cylinders manufactured from aluminium alloys are widely used for the transportation of a variety of gases in a number of applications. This EIGA publication deals with ways of tackling a metallurgical mechanism found in a number of aluminium alloy cylinders, manufactured from aluminium alloys 6351 and 6082, see Appendix 1, which is sustained load cracking (SLC).

In aluminium alloy cylinders this SLC mechanism first became apparent around 1983 when a number of hoop-wound, fibre-wrapped aluminium alloy cylinders burst in USA whilst in use. The cylinders had been manufactured from AA 6351 and were in service for about a year at a pressure of 4500 psi (approximately 310 bar). The cylinders' shells (liners) were manufactured from a billet of aluminium

alloy which had been cast in a re-melt facility. Although compositionally within specification, the lead content was approximately 400 ppm, against less than 30 ppm associated with a billet originating from a smelter facility, where only virgin metal and hardeners are normally combined. Re-melt facilities incorporate scrap aluminium alloy in furnace charges and the lead is believed to have come from free machining aluminium alloy scrap. Consequently, all cylinders in USA made from high lead containing casts, were recalled and destroyed upon receipt [1]¹.

The preliminary conclusions into the failure mode of these cylinders, based on the high lead content were reassessed in the light of a further rupture in February 1984, also of a hoop-wound cylinder, but containing a low lead level (30 ppm). This is to be borne in the light of the then existing specifications, which in the USA stipulated 500 ppm maximum content for lead. Subsequently the specification for lead in USA was lowered to 100 ppm. Even after this move by the USA, it should be noted that considerably lower values were specified in other countries at that time. In both of the examples the failures were as a result of cracks which had initiated in the shoulder area of the cylinder.

Cracks such as these were subsequently also found in the USA and other countries, from 1986 to the present time in aluminium alloy 6351 monolithic, seamless cylinders which were not fibre-wound. This shoulder cracking phenomenon and the formal documentation of yet another, but related, mode of cracking namely neck cracking, promoted discussions and activity in centres of metallurgical research in both the USA and UK. The differences between shoulder cracking and neck cracking are of great importance when assessing future actions.

It should be noted that there has been no recorded incident of a shoulder crack in aluminium alloy cylinders for industrial gases within Europe, however upon examination some diving cylinders have been found to contain such defects on the internal surface. These have at times been the result of abuse such as illegally filling the cylinder to the test pressure.

In 1999 the first example of an SLC mechanism was also reported in the cylindrical section of an aluminium alloy seamless cylinder. Several other similar cracks have been subsequently found, also in AA 6351 cylinders.

Up until now the vast majority of neck cracks have been detected prior to filled cylinders being despatched to the gas users and at the periodic inspection stage. There are no recorded examples within EIGA of neck cracks having given rise to an incident. It should be noted that whereas neck cracks are readily observed during visual examination, it takes considerable expertise to detect shoulder cracks and body cracks.

All forms of cracking, that is the neck, shoulder and body cracking referred to in Section 2, are as a result of the microstructure within the cylinder being exposed to high stresses for extended periods of time. The resultant cracking is intergranular in nature, occurring on grain boundaries, with no evidence of stress corrosion or fatigue. Apart from an early publication [2] little information existed prior to about 1984, after which time considerable resources have been devoted to establishing the causes of the failures.

Neck and shoulder cracks are shown in Appendix 2 and Appendix 3 and appear to be a function of whether the cylinder's neck threads are of a parallel or taper configuration respectively. Hence, the magnitude and manner of the applied stress from the associated valving arrangement are of paramount importance. Cracking associated with the cylindrical part has, to date, only been seen in taper threaded cylinders, but could equally occur in parallel threaded cylinders. Thereafter, micro structural deficiencies within the alloy have an accelerating effect on any eventual failure. Two areas to consider are lead content and manufacturing defects, see 5.1 and 5.3.

5 Metallurgical understanding

5.1 Lead content

An important factor which increases the cracking incidence and hence decreases the time to failure, is the presence of a high lead content. The earlier work by Guttman et al [2] indicated the association of

¹ References are shown by bracketed numbers and are listed in order of appearance in the reference section.