在用车用缠绕气瓶安全性分析

Safety analysis of in-use vehicle wrapping cylinder

北京市特种设备检测中心

BEIJING SPECIAL EQUPMENT INSPECTION & TSETING CENTRE

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背景概述

Background overview

- 天然气取代其他燃料的急迫性
- The urgency of natural gas instead of other fuels

（能源需求、环境需求、天然气自身的安全性）

(Energy demand, environmental requirements, the security of natural gas itself)

- 北京市压缩天然气汽车（CNGV）用气瓶应用的广泛性
- Compressed natural gas vehicles (CNGV) have been widely used in Beijing

- 在用车用缠绕气瓶安全性分析的必要性

- The necessity of security analysis for wrapped cylinders using in vehicles

（1）北京市特种设备检测中心对北京公交总公司使用的车用压缩天然气全复合材料气瓶进行的首次定期检验中，多支气瓶出现外部损伤、泄漏、内胆鼓包、裂纹等问题。

In the first periodic inspection of CNG all-composite wrapped cylinders used by Beijing public transport company , Beijing special equipment inspection & testing center has got the follow data: the defects includes external damage 、 leakage 、 convex 、 cracking etc.

（2）首都北京国际地位的日益提升，对特种设备的安全使用提出了越来越高的要求，而公交车辆上的流动的车用缠绕气瓶的安全性问题更是关系民生的大问题。

- **With the promotion of Beijing's international status, people have higher and higher requirement on the safety of special equipment, the safety issue of the wrapped cylinders is a focus affecting people's livelihood.**


安全第一 预防
严禁烟火

内容
Research contents

- 分析车用缠绕气瓶的失效机理
- Failure mechanism analysis of vehicle wrapping cylinder

方法
Method

- 通过气瓶的性能试验，分析研究气瓶的安全状况；
- Analyzing the safety condition of the cylinder through performance test.
- 通过气瓶酸环境试验、环境介质对气瓶的影响；
- Analyzing the environmental effect through the acid environment test.

- 通过解剖试验及材料性能等试验，分析气瓶失效机理及失效方式；
- **Analyzing the failure mechanism and failure mode of the cylinder through dissection experiment and material performance test.**
- 运用适当的无损检测方法，分析气瓶的安全隐患，为气瓶的安全使用提供技术支撑。
- **Analyzing the potential safety hazard through non-destructive test to provide technical support on safe use of the cylinder.**

1、气瓶爆破强度试验

Burst test

气瓶经过5～9年的使用，受使用过程中的累积疲劳损伤及材料老化的影响，使得大部分气瓶的爆破强度值下降到其设计爆破值以下，但其爆破强度均大于其使用工作压力值的2.5倍。

After used about 5-9 years, the burst strength of more than cylinders decreased to its design value because of the cumulative fatigue damage and the material aging, but the burst strength is more than 2.5 times of the working pressure

这表明该批气瓶的安全裕度仍保持在一个较高的可供使用的水平。

试验中出现的泄漏现象也表明了泄漏问题是气瓶安全使用中应关注的主要失效型式。

It indicated that the safety margin of the batch cylinders remained at high level of availability.

The leakage phenomenon in experiments also showed that the cylinder leakage is a major failure mode which should be concerned in cylinder use .

2、气瓶疲劳循环试验
Fatigue cycle test

气瓶的疲劳循环加载压力为2MPa～26MPa，循环速率 10次/min。

试验结果：大部分试验气瓶实际循环次数可达到7500次而保持未泄漏、破裂。

The fatigue cyclic loading pressure was 2～26MPa, and recycling rate was 10 times/min .

Test result: After 7500 times most of the cylinders didn't appear the phenomenon of leakage and fracture .

可见，气瓶的内密封层的耐疲劳循环加载性能仍保持较好的状态。气瓶强度仍能够达到设计使用压力值的2.5倍以上，爆破位置仍然以封头处开裂居多。

- The cylinders remained good performance in fatigue cycle loading performance test of internal seal layer. The cylinder were still above more than 2.5 times of the working pressure , most break location was in the cylinder's head parts.

3、外表面有超标缺陷气瓶爆破强度试验

Bursting strength test on defects exceeding cylinders in outer surface

- 选取一只气瓶的外表面缺陷尺寸87mm×4.7mm×4.5mm, 位于瓶体中部， 爆破压力值为74.54MPa , 爆破位置在封头，与缺陷位置不吻合。

- The defect size of cylinder outer surface was about 87mm × 4.7mm × 4.5mm and located in the middle part of the cylinder barrel. Bursting pressure value was 74.54MPa. Blasting location was in cylinder head and not same as defect location.

试验结果表明：

现标准中规定的外表面三级损伤缺陷对瓶体强度的影响，应做更为客观的分析和评价，标准中的规定的三级缺陷尺寸较为苛刻。

- The result shows that in the current standard three level damage defect of outer surface should be evaluated objectively for cylinder strength. The regulation of three level damage defect is harsh in current standard.

4、气密性试验

Air tightness test

- 试验结果表明：在用气瓶的气密性质量仍处于可靠的安全状态。
- **The result shows that the air tightness of the cylinders in use is still safe and reliable.**

5、耐酸环境性能试验
Acid resistance test

试验结果表明：

气瓶的耐酸环境性能良好，这也是复合材料耐腐蚀性能较好的体现。

Test result indicates that the acid resistance of the cylinders is good and composite material has good corrosion resistance.

6、极端温度压力循环试验

Extreme temperature and pressure cycle test

气瓶内充入机油，在恒温箱内65℃下恒温保持48小时后对其进行疲劳试验，从2～26MPa循环加载，加载速率3次/min。其疲劳加载次数达7520次而未泄漏。之后将气瓶直接加载至爆破，爆破压力值为56.40MPa，气瓶封头处开裂破坏。

With the cylinder full of oil, in incubator at constant temperature 65℃ ,for 48 hours to keep their fatigue test , loading pressure 2～26MPa . rate 3 times/min ， fatigue loads up to 7520 times without leaking ,after loading the cylinder directly to the blasting ,bursting pressure value 56.4MPa , cracking of the cylinder′s head .

7、裂纹容限试验 Crack tolerance test

试验结果表明：

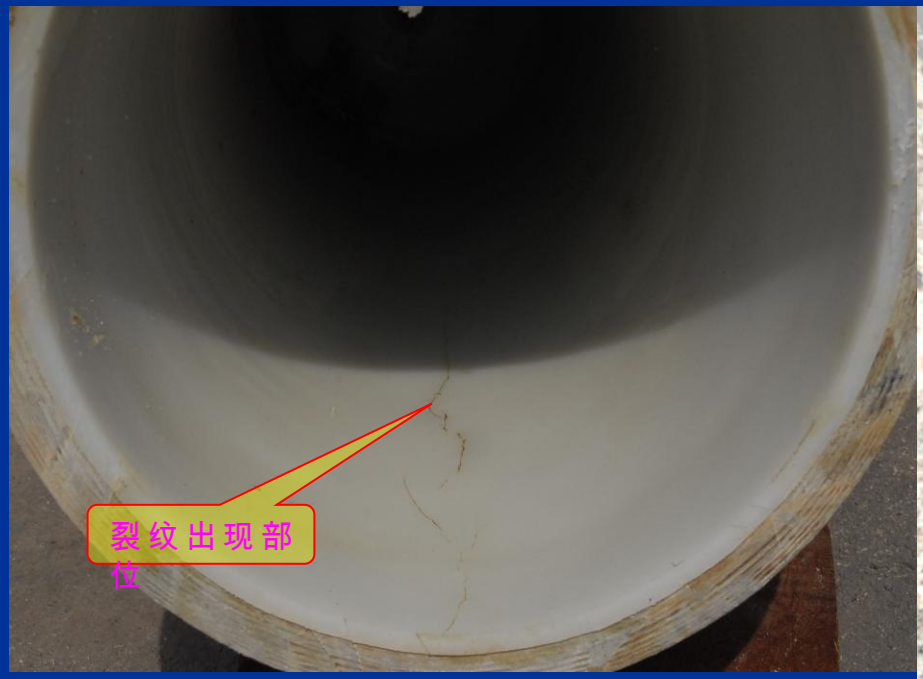
按标准设置的外表面的缺陷对瓶体强度的影响程度处在较低的限度内，没有表现出明显的宏观影响的结果。

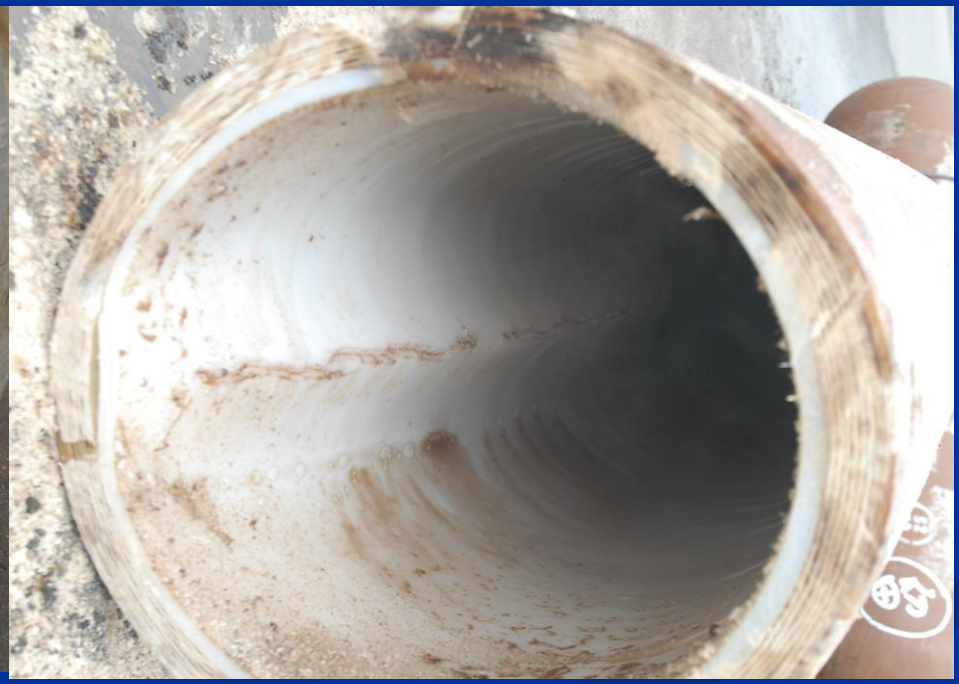
The result shows that the defects of outer surface set by current standard have definite influence on cylinder strength, and there is not obvious effect.

8、解剖试验

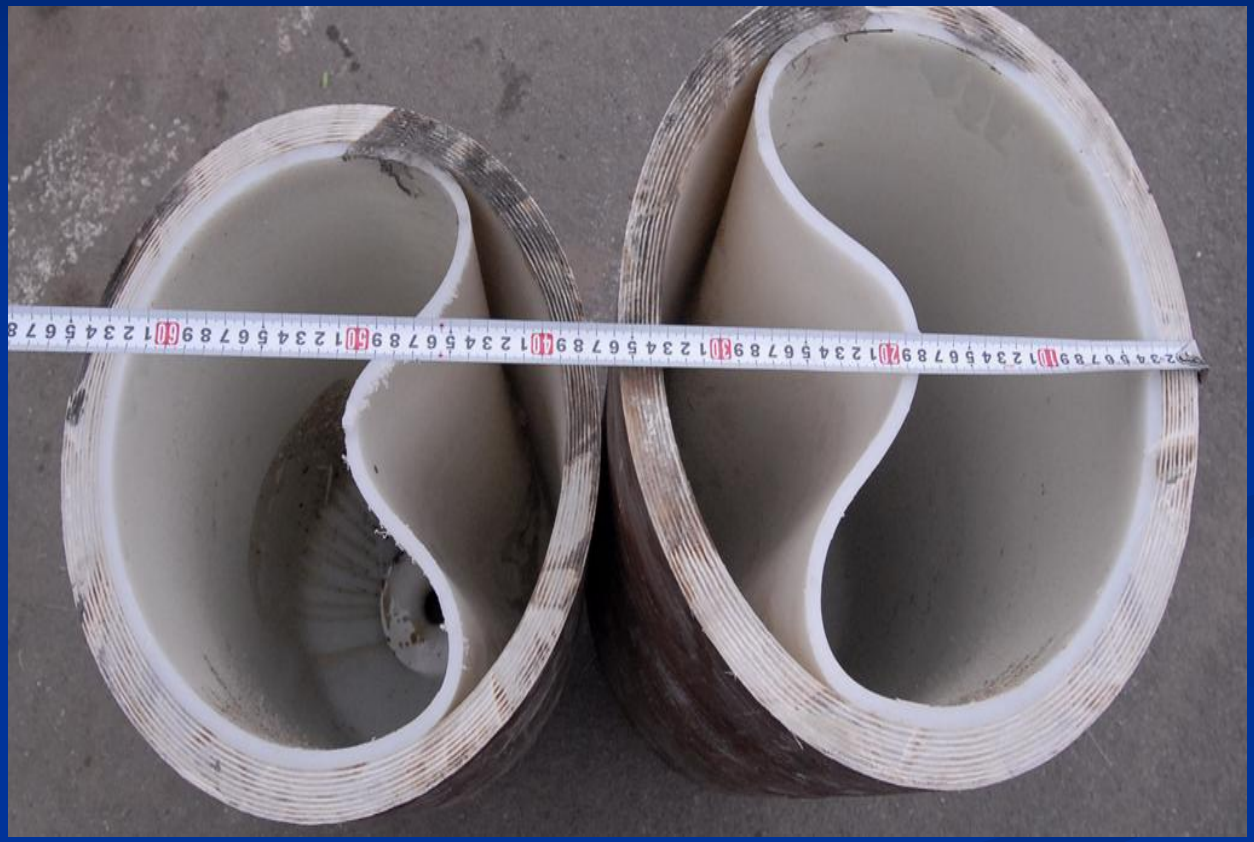
Dissection test

- 内胆出现明显的宏观裂纹
- macro-liner crack

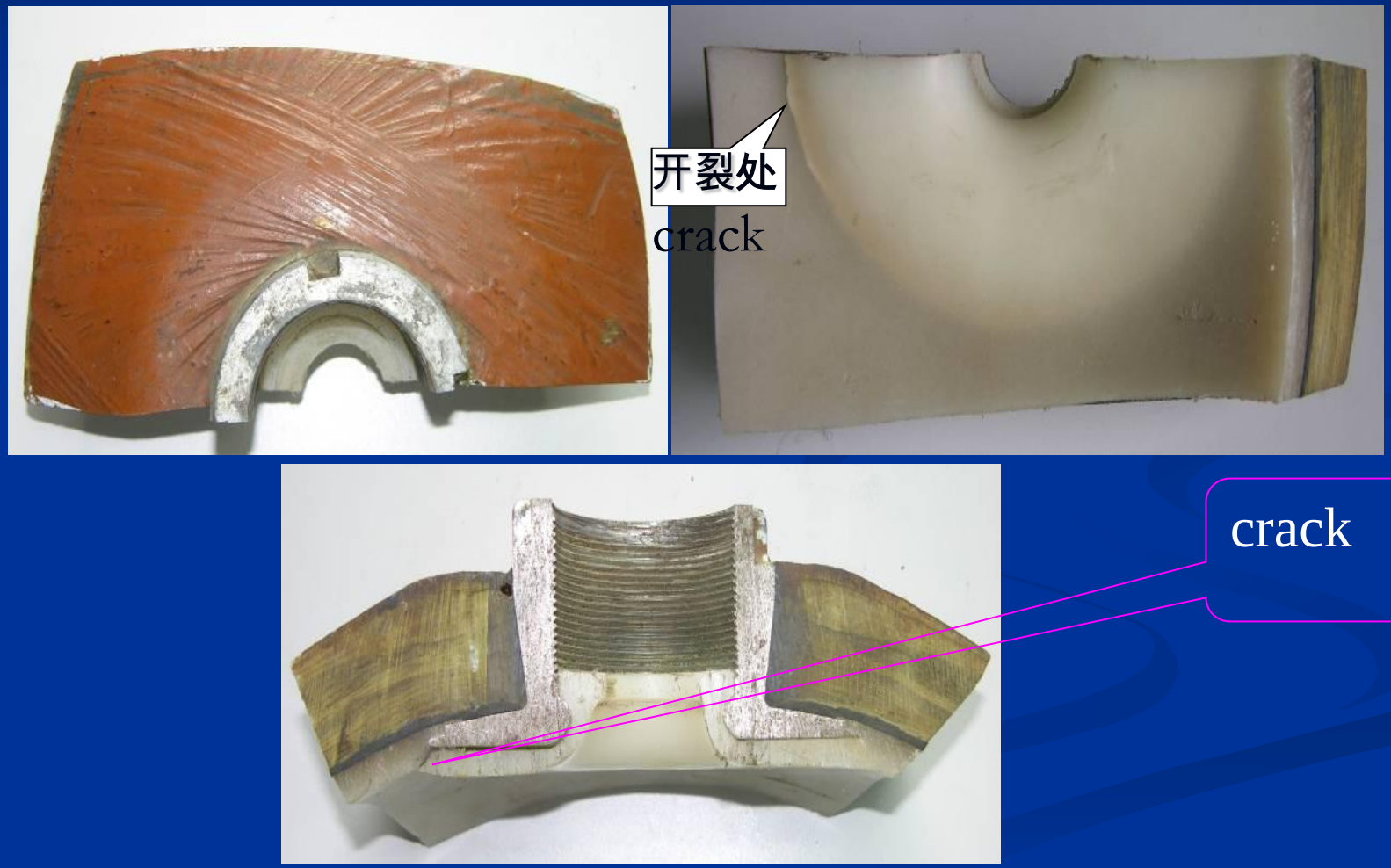




- 内胆形状的改变
- **Shape changing of liner layer**



- 内胆与金属接头的封头部位，有明显的裂纹
- **Obvious cracks in liner and the metal joint head**



9、气瓶塑料内胆材料实验分析

Experimental analysis of plastic liner material

① 内胆材料为聚乙烯，外胆材料为环氧树脂+玻璃或石英纤维。

The liner material is polyethylene, and outer liner is made of epoxy resin and glass or quartz fiber.

② 内胆材料70℃时的拉伸强度约为常温时的50%，模量约为常温时的34%； - 20℃时的拉伸强度约为常温时的1.6倍，模量约为常温时的2倍。

Tensile strength of liner material at 70 ℃ is about the 50% of the normal temperature , and modulus is about 34% of normal temperature. At -20 ℃ the tensile strength is about 1.6 times of the normal temperature, and modulus is about 2 times of the normal temperature.

③ - 20℃~70℃温度范围内内胆材料的平均线膨胀系数均为外胆材料的10倍以上。

Between -20℃ and 70℃ the average linear expansion coefficient of liner material is over 10 times of outer refill.

④ 气瓶使用过程中的温度变化、充放气过程以及内外材料膨胀系数相差较大的影响会使内胆薄弱部位重复温升—膨胀—失稳—翻转的变形过程，且翻转变形量会增加，

- The temperature fluctuation during the using process of cylinders, inflation and deflation process and the difference of material expansion coefficient between inside and outside of cylinders have influence on the weak part and make it repeat the deformation process of temperature rise – expansion – failure – reversal, and deformation would increase gradually.

- 多次循环后当变形量超过材料的变形极限时翻转区域内表面或折皱区域即会产生损伤开裂，最终发生泄漏失效，这也就是鼓包最终形成裂纹的过程。

- **After multiple cycles when the deformation exceeds the deformation limit of the material , damage fracture will be occurred and finally lead to leak failure. It is the process from convex hull to the crack formation.**

10、气瓶工业CT检测试验

Industrial CT test of cylinders

气瓶在内压为4.8MPa结果。气瓶内衬层外表面且贴合良好，内衬层结构完整。从图中可见内衬层的厚度稍显不均匀。外复合材料缠绕层厚度及结构均匀，无异常。

The slice of cylinder at internal pressure of 4.8 MPa indicates that the outer surface of cylinder liner is good attaching with inner liner layer and structure of inner liner is complete. It can be seen that the thickness of cylinder liner is slightly uneven . The outer wrapping layer of composite material has uniform thickness and normal structure.

气瓶在内压为2.3MPa下结果。气瓶内衬层与外表面且贴合良好，内衬层结构完整。从图中可见内衬层的厚度稍显不均匀。外复合材料缠绕层厚度及结构均匀，无异常。

T`he slice of cylinder at internal pressure of 2.3 MPa indicates that the outer surface of cylinder liner is good attaching with inner liner layer, and structure of inner liner is complete. It can be seen that the thickness of cylinder liner is slightly uneven . The outer wrapping layer of composite material has uniform thickness and normal structure.

气瓶在内压为1MPa下的结果。气瓶内衬内鼓明显，内鼓的幅度达到了气瓶内径的1/5以上。内鼓变形的位置大约出现在内衬壁厚的较薄处。外复合材料缠绕层厚度及结构均匀，无异常。

The slice of cylinder at internal pressure of 1 MPa indicates that the convex of cylinder liner reaches the 1 / 5 diameter of cylinder, and the deformation is around the less thickness of the cylinder. The outer wrapping layer of composite material has uniform thickness and normal structure.

气瓶在内压为1MPa下的中部的结果。气瓶内衬内鼓明显，内鼓的幅度达到了气瓶内径的3/5以上。内鼓变形的位置大约出现在内衬壁厚的较薄处。外复合材料缠绕层厚度及结构均匀，无异常。

The slice of the middle of cylinder at internal pressure of 1 MPa indicates that the convex of cylinder liner reaches the 3 / 5 diameter of cylinder, and the deformation is around the less thickness of the cylinder. The outer wrapping layer of composite material has uniform thickness and normal structure.

气瓶内衬结构状况随着压力的变化发生了明显的变化。内压在2.3MPa以上时，气瓶内衬的形状保持原状，且与外缠绕强度层贴合紧密。随着气压的降低，有可能逐步出现内衬的“内鼓”现象，这种内鼓的程度在瓶体的前、中、后部位不一样。当内压降低到约为1MPa时，出现内衬层明显的“内鼓”变形。

Cylinder 's liner with the pressure changes the situation significantly changes occurred . In the above internal pressure 2.3MPa , the shape of cylinder liner to maintain the status quo , and with the outer layer fit tightly wound strength . As the pressure to reduce , which may gradually appear lined with "convex" phenomenon, the extent of this within the convex body in cylinder before, during and after the position is different , When the internal pressure decreased to about 1MPa, the inner layer appears obvious " convex " deformation.

在用车用缠绕气瓶的安全性分析

Safety analysis of in-use vehicle wrapping cylinder

全塑CNG复合材料气瓶的失效模式及分析

CNG cylinder failure mode and analysis

主要失效模式：

Major failure modes :

- 封头破坏、筒体破坏（复合材料强度层失效）
- **Damage of head and barrel (failure of composite material layer)**

- 泄漏（塑料内胆失效）
- **Leakage (failure of plastic liner)**
- 气瓶金属接嘴的松动（气瓶结构失效）
- **Looseness of cylinder metal tipped (failure of cylinder structure)**

其中泄漏是最主要的失效模式，其产生原因主要为：

Leakage is the major failure mode with the following causes：

- 塑料内胆中预先存在的缺陷
- Pre-existing defects in the plastic liner
- 使用过程中的疲劳损伤
- Fatigue damage of the using process

影响车用缠绕气瓶使用安全性的重要因素

Main factors affecting the use safety of vehicle wrapping cylinders

- 全塑CNG复合材料气瓶的内胆质量
- The liner quality of CNG cylinders
- 气瓶接嘴部位的质量
- The quality of the cylinder tipped parts

- 外缠绕复合材料强度层的质量
- The quality of outer winding layers of the composite material strength
- 气瓶的成型质量一致性
- The consistency of cylinders molding
- 气瓶的使用环节因素
- The use factors of cylinders

结论：Conclusions

- 1. 车用缠绕气瓶经过前期使用，其剩余强度（爆破强度）有不同程度的下降，但气瓶整体安全性仍处于符合使用条件的状态。

- After the early using stage, residual strength of cylinders decreased in varying degrees, but the cylinder is still under service conditions.

- 2. 车用全塑缠绕气瓶的失效报废因素主要是塑料内胆的失效所致，其报废因素主要有：
- The main failure factor of cylinders is the plastic liner failure, and the following factors cause liner failure :

- ①气瓶内胆质量缺陷，气瓶内胆鼓包、裂纹、密封泄漏等:
- Quality defects of the cylinder liner, including liner convex, crack, sealing leaking etc.
- ②气瓶的外表面损伤（筒身段裂纹、断丝、冲击凹坑等）；
- Damage of the outer surface of cylinder (posture crack , broken wire , impact pits , etc.).
- ③气瓶金属接嘴松动;
- Looseness of cylinder metal tipped.

- 3. 影响车用缠绕气瓶安全性的主要因素有：
- Main factors affecting the safety of cylinder

- ①内胆的质量可靠性；
- The reliability of cylinder liner
- ②气瓶接头部位的质量可靠性；
- The reliability of cylinder joints

- ③气瓶的外缠绕层的剩余强度；
- Residual strength of winding layer around the cylinder
- ④使用过程中的意外因素（外表面损伤、整体振动冲击等）。
- Unexpected factors in use (external surface damage , vibration and impact , etc.)

- 4. 在众多影响气瓶使用安全可靠性因素中，气瓶的失效往往发生在其质量最薄弱的位置和环节。气瓶的内胆质量、结构设计质量及成型制造质量等问题，使气瓶整体的高质量受到限制，从而影响了气瓶整体的安全可靠性。
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- In the factors that affect the safety and reliability of the cylinders in use, the failure usually occurs in the weakness of the cylinders. The issues of cylinder's liner quality , structure design quality and machining quality affect the quality of cylinder , and affect the safety and reliability of cylinder.

谢　　谢

Thank you!