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Failure analysis of massively failed compressed air cartridge

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ABSTRACT

Aim of the analysis was to determine the cause of massive failure of compressed air cartridge in respect to used material, quality of stock, its chemical composition, mechanical properties and quality of inner surface of the component. Furthermore, comparative analysis of identical component fabricated prior to innovation of fabrication technology was carried out.

The study describes corrosion attack documented on the component – pitting corrosion and evaluates connection between its appearance and microstructure of used material, surface quality, change in design and presence or lack of surface treatment namely anodic oxidation.

Part of the analysis is a theoretical calculation of the real load applied on compressed air cartridge, with respect to state and quality on inner surface, in real operating conditions. Light microscopy and scanning electron microscopy techniques were used for microstructural assessment as well as fractographic analysis.

1. Introduction

Airguns are very popular for sports and competition shooting. Integral part of the airguns is air cartridge with capacity circa 140 shots. The average cartridge pressure is therefore relatively high, usually circa 200 bar. For cartridge testing, pressure of about 280 bar is used and this will be considered as normal pressure value in the article, as it is safety value guaranteed by the producer. But it is common practise, that airguns are not used according to handling instructions. For example, air guns are improperly stored or the air cartridges are, in order to increase its shoot capacity, filled to a pressure, which is higher than pressure specified by manufacturer. Therefore, selection and quality of cartridge material is even more critical for the quality of final product.

This study deals with not optimal change of material and technology for air cartridges production, which, together with improper manipulation, resulted in a failure and following explosion of air cartridge. Appearance of the cartridge that was left in the case at direct sunlight on the premises of shooting range and exploded is shown in Fig. 1. As can be seen, not only cartridge, but also gun case and shelf that case was placed on were damaged. Besides, roof of the object that gun case was placed in was also damaged.

The aim of manufacturer was implementation of more economical cartridge production method. Original cartridge, weld of two bases with the middle tube part, was replaced by compact piece, machined from the bar stock. Therefore, AW 7075 (AlZn5.5MgCu) bar stock was used instead of former AW 6082 (AlSi1MgMn) round tube stock.

Generally, Al-Zn-Mg alloys belong to the aluminium alloys with highest strength and have greatest potential for the age-hardening of all aluminium alloys. Such alloys have good cold-working properties and usually, they are not sensitive to cooling rate. However some of those alloys are susceptible to intercrystalline corrosion and exhibit higher notch sensitivity than Dural [1–5]. Basic properties of both materials are shown in Table 1.

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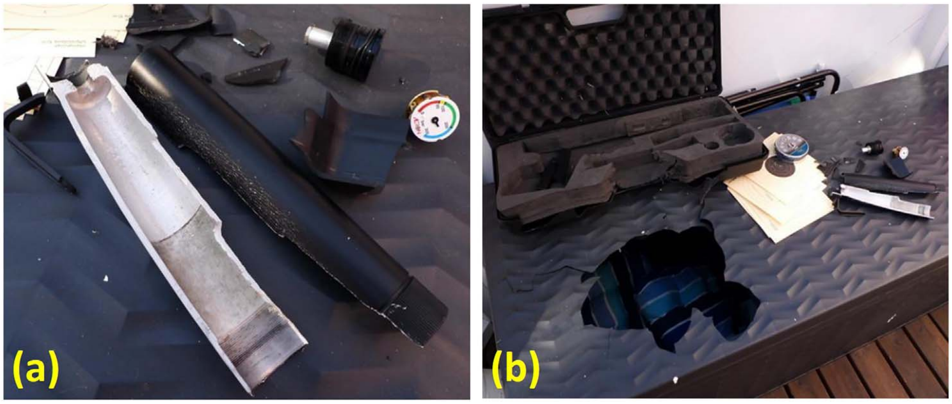

Fig. 1. (a) Appearance of exploded cartridge, (b) appearance of gun case and shelf, on which the case was placed.

2. Material and methods

Two air cartridges were subjected to comprehensive analysis. Failed cartridge produced by later production process i.e. machined from the bar stock, was designated as component A. For comparison, cartridge from former production batch, fabricated from AW 6082 round tube stock, was also analysed and designated as component B.

Sectioning of components was carried out on a precise cut-off machines Struers Discotom 5 and Accutom, using intensive cooling. Samples for metallographic assessment were prepared in the usual way using automatic grinding/polishing machine Struers Tegramin. Samples were wet ground with silicon carbide papers, polished with Struers diamond suspensions and finally polished using colloidal silica suspension. To reveal the microstructure, Fuss etchant was used.

For microstructural evaluation and documentation, 3D opto-digital microscopes with high resolution OLYMPUS DSX510 and DSX110 were used. Further fractographic analysis was carried out using scanning electron microscope Philips XL 30.

In order to better understand the notch effect of corrosion pits and non-standard increase of inner pressure in the cartridge on both analysed materials, 2D axisymmetric finite element study was conducted modelling the cartridge as a closed pressure vessel with an inner circumferential notch. The dimensions of the notch were derived from a typical corrosion pit observed on the failed cartridge. Constant pressure was applied on the inner surface of the vessel. Material parameters were obtained from previous research by Mazal et al. [5], who compared mechanical properties of both AW 6068 and AW 7075 aluminium alloys.

3. Results

3.1. Component A, machined AW 7075 bar stock

Appearance of the failed cartridge is shown in Figs. 2 and 3. Corrosion of inner surface of the cartridge is clearly visible in the area of cartridge base and also in the thin-walled area (see Fig. 3). Secondary cracks were observed in the area of transition from the base to the thin-walled part of component. Besides the cracks, notch, which was clearly caused by inappropriate machining process was revealed as can be seen in Fig. 3b. Detailed documentation of the defects via SEM is shown in Fig. 4.

Microstructure of failed component in different areas is documented in Fig. 5. Microstructure consists of solid solution α and Al, Zn, Mg and Cu based precipitates. Severe corrosion pits were observed on all inner surface of the cartridge and as can be seen in Fig. 5a and b, corrosion pits depth was up to 280 μm. Thick oxide layer (~40 μm) obtained by anodic oxidation was observed only on the outer surface of the component (see Fig. 5d). No corrosion damage or any other surface defects were observed on outer surface.

In order to reveal influence of material microstructure on fracture mechanism, fractographic analysis of failed cartridge was performed. Fracture surface morphology was identical in all observed locations. Fracture can be characterized as ductile, with typical woody fracture morphology, which is related to forming texture (see Fig. 6). Initiation site of the crack was not revealed.

Table 1
Basic properties of aluminium alloys AW 7075 and AW 6068 [1–5].

	AW 7075	AW 6068
UTS [MPa]	470–560	270–310
YS [MPa]	400–500	200–260
hardness	150 HBW	95 HBW
Temperature limit for long/short-term loading	90/120 °C	120/160 °C