PROBLEMY MECHATRONIKI
UZBROJENIE, LOTNICTWO, INŻYNIERIA BEZPIECZEŃSTWA

ISSN 2081-5891

11, 1 (39), 2020, 91-102

PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

Results of Wear Evident in the Gun Barrel Bore of the Leopard 2A4 Main Battle Tank

Aleksander J. WASILEWSKI[*1], Ryszard B. WOŹNIAK[2], Janusz WEISS[1], Józef GACEK[2]

[1]Military Institute of Armament Technology
7 Prymasa St. Wyszyńskiego Str., 05-220 Zielonka, Poland
[2]Military University of Technology,
Faculty of Mechatronics and Aerospace, Institute of Armament Technology
2 Sylwestra Kaliskiego Str., 00-908 Warsaw, Poland
[*]Corresponding author's e-mail address and ORCID:
wasilewskia@witu.mil.pl; https://orcid.org/0000-0001-5706-6869

Received by the editorial staff on 13 March 2019
The reviewed and verified version was received on 4 March 2020

DOI 10.5604/01.3001.0014.0289

Abstract. Dynamic Testing Centre of Military Institute of Armament Technology (MIAT, Zielonka, Poland) runs dynamic tests and research for many years. Tests are conducted for armament industry, Polish Army and for scientific purposes. The influence of construction, exploitation, technology factors for 120 mm Rh-120 L44 durability is one of the area of interest of MIAT. 120 mm Rh-120 L44 cannon is a primary weapon of Leopard 2A4 and 2A5 tanks. These tanks in total number of 247 (142 - Leopard 2A4 and 105 Leopard 2A5) are in use of Polish Army since 2002.

This work has been compiled from the paper presented during the 12th International Armament Conference on Scientific Aspects of Armament & Safety Technology, Jachranka, Poland, September 17-20, 2018

In the paper analysis of Leopard 2A4 L44 cannon barrel's bore wearing out using Polish and foreign production ammunition was presented. The analysis was made basing on document TDv18 which is specifying the conditions affecting on taking out of a service decision. These conditions are: boundary of wearing out barrel material and specifying the number of shoots after exceeding, the fatigue of material will achieve critical value.
Keywords: artillery system, testing of barrels, exploitation of artillery

1. INTRODUCTION

The German-made Leopard 2A4 and 2A5 main battle tanks feature the Rh-120 L44 main gun and have been operated by the Polish Army since 2002. The tanks are classified as "prospective development technical assets". The understanding of selected aspects of the operation of the Leopard tanks is not only an interest of researchers, but also a necessity dictated by the operating practice of these main battle tanks.

During its operation (firing), the barrel bore of the tank's gun is gradually worn. This results in a gradual degradation of the ballistic performance of the gun barrel. Each shot causes erosion in the barrel bore. The erosion originates from a strong impact from the reactions of propellant charge combustion gases, a high combustion temperature of the propellant inside the bore, and a high muzzle velocity of the projectile [1-3]. The service life (durability) of the gun also depends on factors within the control of the gun barrel user: the total number of rounds fired, the type of ammunition, the size of the propellant charge, the rate of fire, and the methods of barrel bore cleaning, maintenance and repairs.

Table 1. Essential characteristics of the Rh-120 L44 gun [1]

Specification	Units	Criterion
Gun type	-	smooth-bore
Breech type	-	Sliding vertical wedge
Calibre	mm	120
Barrel length	mm	5 300
Recoil length	mm	290 – 350
Gun weight	kg	3 800
Ammunition type	-	120x570 mm, fixed, with partially combustible casing
Compatible projectile types	-	DM-18A (HEAT / shape-charged) DM-33 or APFSDS-T (discarding sabot projectile) HE (high explosive)

Micro cracks develop within the barrel bore. This happens without any external factors. This is caused by the deposited chrome plating, exposed to tensile stress each time a gun round is fired. Whenever the tensile stresses are relaxed, the lattice of the micro cracks is expanding.

The micro cracks propagate from the chrome plating material to the base metal. Hence, the manufacturing stage of the gun barrel requires special heat treatment once the chrome plating is formed within the barrel bore. The essential characteristics of the Rh-120 L44 gun [1] are listed in Table 1.

2. CHARACTERISTIC WEAR SYMPTOMS OF GUN BARREL BORE

Depending on the design, structure, manufacturing process, materials and operating conditions, the wear of a gun barrel bore can be evident in a number of ways. In the case of the Rh-120 L44 gun barrel, the wear is most evident by:

- damage to the chrome plating of the barrel bore;
- damage from material fatigue.

2.1. Wear of the barrel bore chrome plating

The characteristic wear symptoms of the chrome plating in the gun barrel bore include:

- Heat crack lattice: micro fractures penetrating the chrome plating layer and the barrel base metal down to several millimetres. A heat crack lattice is formed under extremely high temperatures and under combustion gas pressure when a gun round is fired. The primary heat crack lattice is formed already during the production of a gun barrel.
- Blisters: or the detachment of the chrome plating from the base metal.
- Chrome flaking: this wear form results from the detachment of pieces of the chrome plating, followed by their expulsion from the barrel bore by the force of fired rounds.
- Delamination: a considerable portion of the chrome plating is ripped off the substrate when the heat crack lattice becomes considerably large.
- Purging: the barrel bore material is ripped off and removed forcibly as a consequence of erosion.

The aforelisted superficial wear damage of the barrel bore is highly dependent on the temperature of propellant combustion gas, the projectile velocity along the bore, and the pressure of propellant combustion gas.

The practice of artillery firing dictates that the initial velocity of APFSDS-T-TP discarding sabot projectiles is approximately 1680 m/s, and the initial velocity of HE projectiles is approximately 950 m/s. This means that the firing of discarding sabot projectiles imposes a strain on the gun barrel much higher than the firing of full-calibre projectiles. The velocity and pressure of propellant combustion gases might locally achieve higher values, e.g. at the locations of geometrical changes of the barrel bore (the free bore).

2.2. Damage from material fatigue

Material fatigue is the degradation of material crystalline structure as an effect of dynamic loads. Visual evidence of material fatigue has the form of micrometric cracks which develop after a number of shots. Each next shot propagates the fatigue cracks in multiple directions. Once a critical number of dynamic load cycles is achieved, a crack through the gun barrel develops, leading to rupturing of the barrel. In practical terms, the number of shots is specified significantly below the critical number of shots (i.e. dynamic load cycles) at which the barrel will rupture.

3. GUN BARREL TEST METHODOLOGY

Gun barrels are tested and examined to verify their fitness for continued service and assign the gun barrel to a specific wear category. A gun barrel is disqualified from further service whenever:

- the ballistic performance is reduced below the minimum limits (i.e. the initial projectile velocity is reduced by 10%, the barrel internal pressure is reduced below the detonator priming pressure, and/or the permitted projectile scatter is exceeded);
- the gun fails to operate properly due to the actual wear of the barrel bore, or the operating safety would be compromised by continued firing;
- the fatigue life (defined by the limit number of shots) is exceeded;
- other defects occur which prohibit further service of the gun barrel.

The testing of barrel bore quality is most often based on the visual inspection of the bore surface, measurements of the bore dimensions, indentation testing of the bore surface, and measurements of the bore surface and depth of pitting. The test methodology applicable to the Rh-120 L44 gun barrels is specified in Tdv 018 Maintenance Manual, commonly used by NATO. The Tdv 018 Maintenance Manual specifies the general and special aspects of the operation and technical inspection of the gun barrels in service of the NATO forces. The Tdv 018 Maintenance Manual was a reference source for the tests carried out at the Dynamic Testing Centre of the Military Institute of Armament Technology (MIAT, Zielonka, Poland).

4. TEST RESULTS OF THE Rh-120 L44 GUN BARREL BORE

Three barrels of the Rh-120 L44 tank gun were tested (Photo 1). The test comprised a visual examination of two sections of the calibre length of each barrel bore (Fig. 1). First, the section located directly downstream of the free bore was inspected (up to 150 mm), followed by the inspection of a section within the area of bore evacuator ports (Fig. 1).

The selected test sections were characterised by elevated exposure to propellant combustion gases, which made a visual examination of their effects relatively straightforward.

The visual examination was performed with a General Electric Mentor Visual IQ borescope.

Photo 1. Rh-120 L44 gun barrel on a test rig

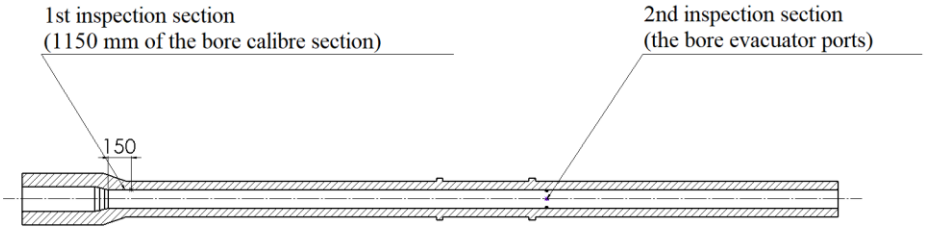

Fig. 1. Cross-sectional diagram of the Rh-120 L44 gun barrel bore with the inspection sections highlighted

4.1. Examples of the test results for gun barrel #1

The tested gun barrel #1 had a total of 635 shots fired, with 333 shots of HE ammunition, 225 shots of APFSDS-T ammunition (filled with German-made propellant powder), and 77 shots of APFSDS mock projectile ammunition.

Test result: the section downstream the free bore (Photo 2) featured (a) evidence of heavy purging of the bore surface with spalling and cracks, and (b) evidence of an extensive heat crack lattice.

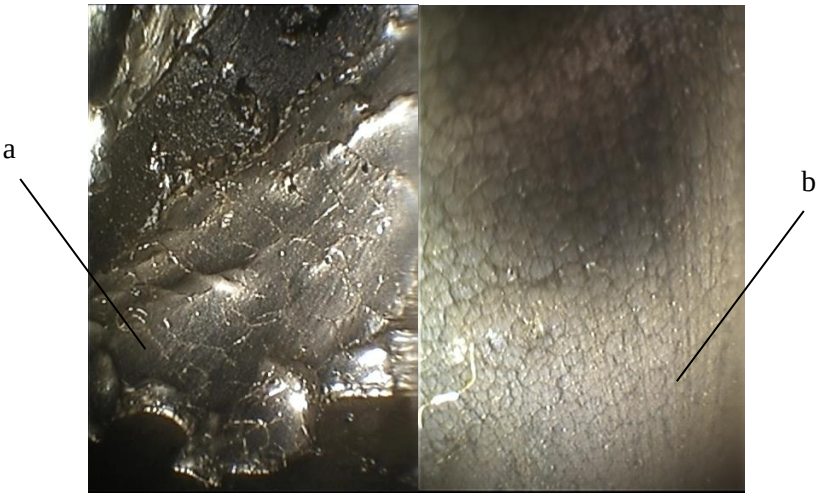

Photo 2. Condition of the full-calibre bore section downstream of the free bore (gun barrel #1)

The section in the area of the bore evacuator ports featured erosion indications in the form of purging and delamination of the bore surface. The erosion indications were approx. 15 mm in length (Photo 3).

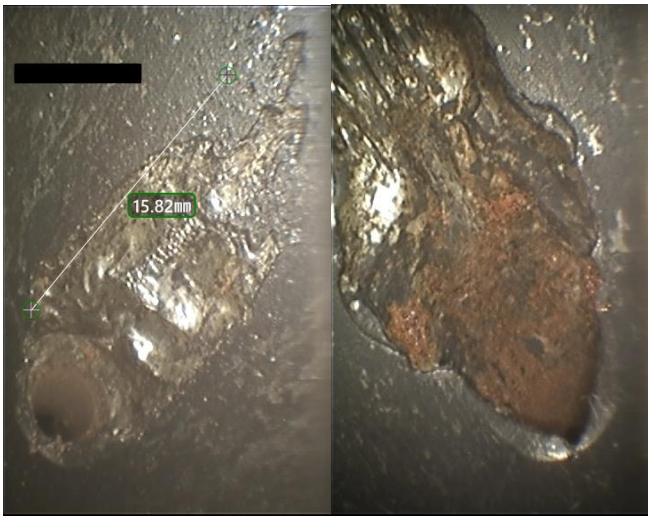

Photo 3. Condition of the bore evaluator port area (gun barrel #1)

According to [1], the barrel failed to meet the ballistic performance criteria and continued firing might compromise the safety of the tank gun crew.

4.2. Examples of the test results for gun barrel #2

The tested gun barrel #2 had a total of 684 shots fired, with 248 shots of HE ammunition, 320 shots of APFSDS-T ammunition, and 116 shots of HE mock projectile ammunition.

Test result: the section downstream the free bore (Photo 4) featured (a) very evident indications of pitting and cracks with many indications of spalling and purging; the recessed revealed (b) indications of corrosion. Multiple (c) blisters and (b) splinters were also found.

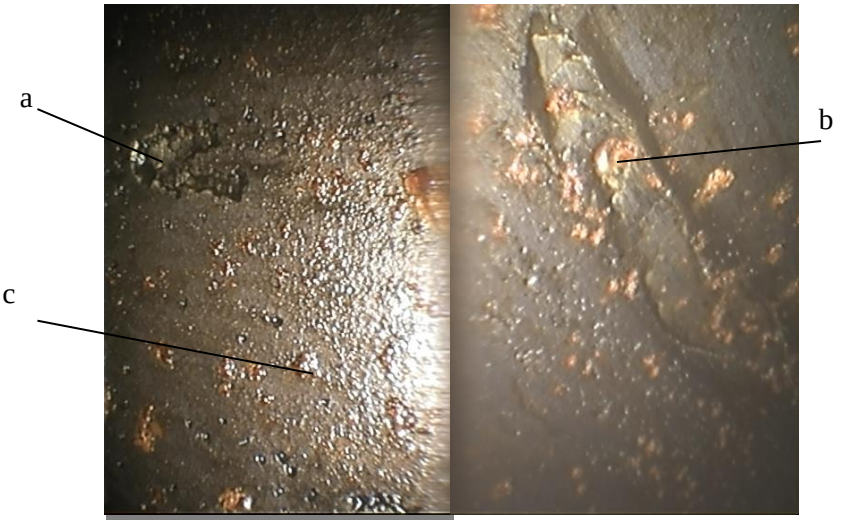

Photo 4. Condition of the full-calibre bore section downstream of the free bore (gun barrel #2)

The section in the area of the bore evacuator ports featured readily visible evidence of irregular purging. Here, evidence of highly advanced corrosion was found. Directly at the bore evacuator ports, visible defects of material were found (Photo 5). The damage found in gun barrel #2 disqualified it from continued service.

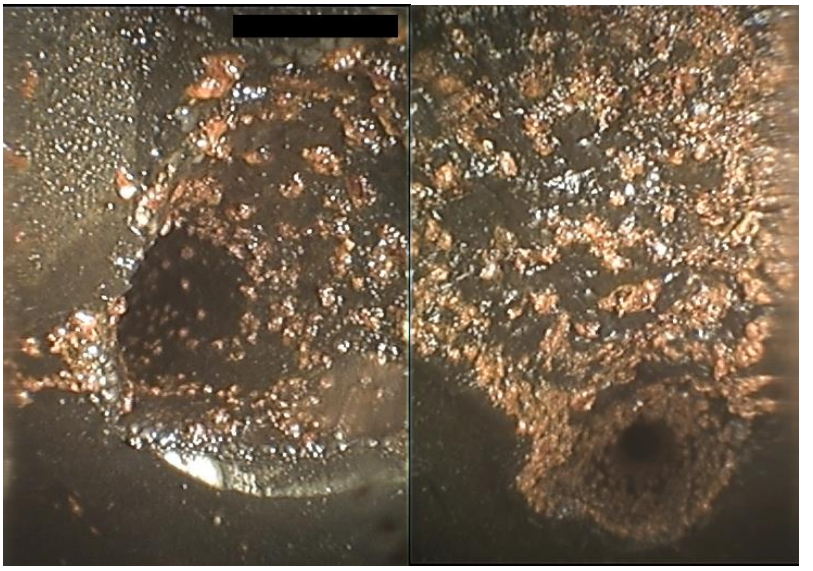

Photo 5. Condition of the bore evaluator port area (gun barrel #2)

4.3. Examples of the test results for gun barrel #3

The tested gun barrel #3 had a total of 535 shots fired, with 189 shots of HE ammunition, 261 shots of APFSDS-T ammunition, and 85 shots of assorted HE mock projectile ammunition types.

Test result: the section downstream the free bore (Photo 6) featured evidence of (a) spalling with (b) delamination and flaking of the barrel bore surface. There were also clear indications of a heat crack lattice. The section in the area of the bore evacuator ports (Photo 7) revealed strong purging of the bore surface with extensive cracks underneath. The geometric features of the bore evacuator ports were altered. Gun barrel #3 was in continued service at the Dynamic Testing Centre of the Military Institute of Armament Technology. A list of all shots fired with the tested gun barrels is shown in Table 2.

Table 2. List of all shots fired with the tested gun barrels

Projectile type	Gun barrel #1	Gun barrel #2	Gun barrel #3
HE	333	248	189
APFSDS-T	225	320	261
Mock HE	77	116	85
Total	**635**	**684**	**535**

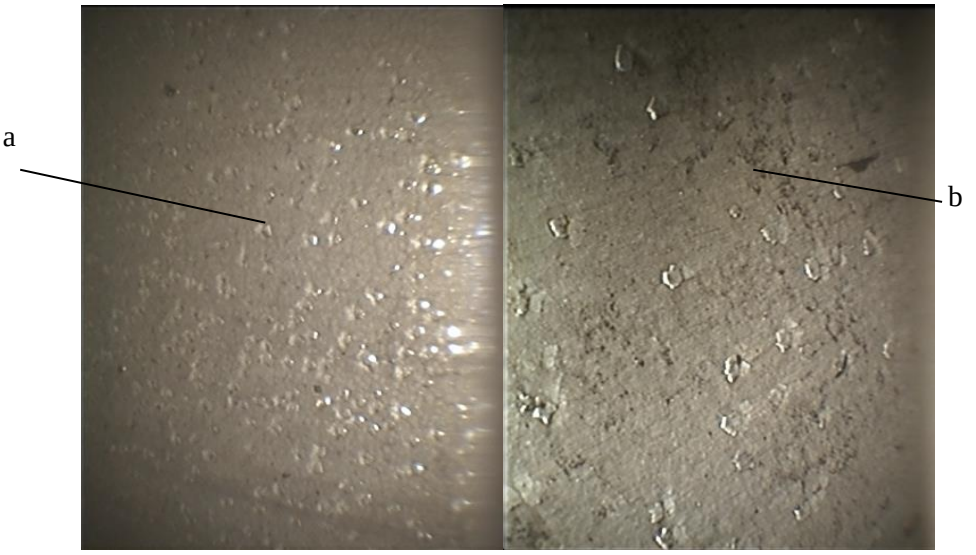

Photo 6. Condition of the full-calibre bore section downstream of the free bore (gun barrel #3)

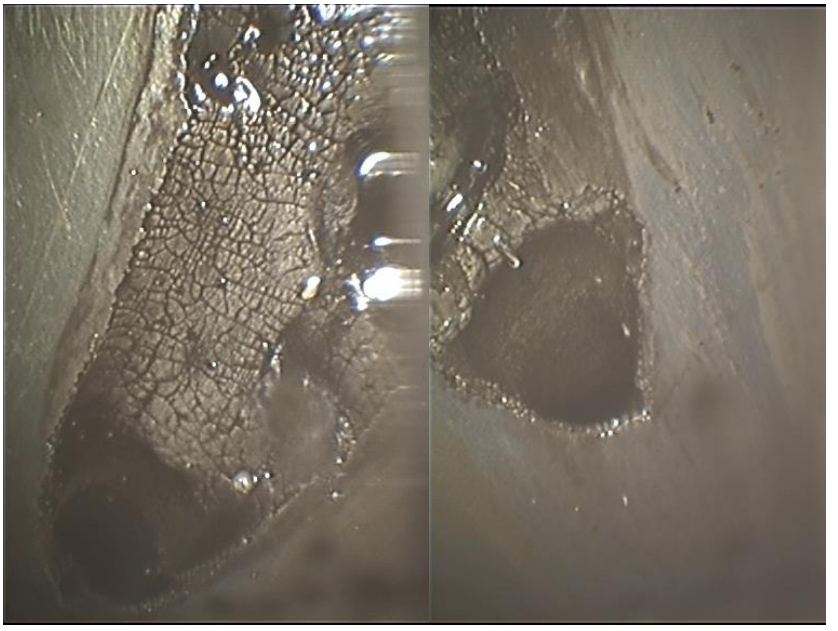

Photo 7. Condition of the bore evaluator port area (gun barrel #3)

5. SUMMARY AND CONCLUSIONS

1. The analysis of the test results for the Rh-120 L44 gun barrels revealed that the ballistic performance of gun barrel #1, which had fired 635 projectile rounds, and gun barrel #2, which had fired 684 projectile rounds, deteriorated to a level which would compromise the safety of the crew. It was decided to decommission both gun barrels.
2. Gun barrel #3 had fired a total of 530 projectile rounds and was found to gradually lose its specified ballistic performance. It should be expected that approximately 150 future rounds of APFSDS-T and/or HE projectiles will cause evidence of wear comparable to that in gun barrel #1 and #2.
3. The photographs shown here provide an image of the characteristic test results only. They substantiated the conclusion that the bore of gun barrel #2 had the evidence of heaviest wear of all gun barrels tested. Gun barrel #1 featured erosion indications less advanced that in gun barrel #2. This was caused by the number of total shots lower by 49 than in gun barrel #2, and what was more significant, gun barrel #1 fired 95 rounds of discarding sabot projectiles less than gun barrel #2 (according to the data from [1] for the Rh-120 L44 tank gun, a HE projectile round shot wears the barrel bore by 30% less than one APFSDS-T projectile round shot). [1] also states that the maximum limit of APFSDS-T shots is 1500, and the first technical inspection of the gun barrel shall be done after 800 shots, unless evidence exists to prompt an earlier inspection.
4. Based on the proprietary examination of barrel firing completed so far at the Stalowa Wola Dynamic Testing Centre of the Military Institute of Armament Technology (Zielonka, Poland), a gun barrel equivalent wear rate was adopted which indicated that one discarded sabot projectile shot corresponds to a minimum three HE projectile shots. Given the foregoing, it could be assumed that gun barrel #1 and gun barrel #2 had 1085 and 1324 HE projectile-equivalent shots fired, respectively.
5. Further investigation into the problem discussed herein will be to determine the effect of firing mock HE and APFSDS-T projectiles on the wear of the gun barrel bores. The results of the future investigation should develop a test methodology for the determination of the gun barrel bore wear rate for firing Polish-made gun ammunition. This, in turn, will help the Inspectorate for Armed Forces Support optimise the scheduling of gun barrel overhaul and replacement for the Leopard 2A4 and 2A5 tanks in service of the Polish Army.

FUNDING

The authors received no financial support for the research, authorship, and/or publication of this article.

REFERENCES

[1] „Dokumentacja Techniczna TDv 018 – Ocena luf broni kalibru 5,6 mm do kal. 203 mm". 1983. Materialamt des Heeres.

[2] Idziaszek Zdzisław, Roman Stelmasiak, Janusz Sitek, Ryszard Woźniak. 2002. Analiza wpływu parametrów konstrukcyjnych układu lufa-pocisk na trwałość lufy. W *Materiały IV Międzynarodowej Konferencji Uzbrojeniowej nt. „Naukowe Aspekty Techniki Uzbrojenia"*. Warszawa: Wydawnictwo Wojskowej Akademii Technicznej, 252-261.

[3] Idziaszek Zdzisław, Roman Stelmasiak, Janusz Sitek, Ryszard Woźniak. 2002. Analiza czynników determinujących trwałość lufy w aspekcie zwiększenia niezawodności broni. W *Materiały III Konferencji Naukowo Technicznej nt. „Badania i rozwój systemu BM-21 oraz nowoczesnej amunicji".* Poznań: Wydawnictwo Politechniki Poznańskiej, 153-165.

Wyniki zużycia przewodu lufy armaty czołgu Leopard 2A4

Aleksander J. WASILEWSKI[1], Ryszard B. WOŹNIAK[2],
Janusz WEISS[1], Józef GACEK[2]

[1]Wojskowy Instytut Techniczny Uzbrojenia
ul. Prymasa Stefana Wyszyńskiego 7, 05-220 Zielonka
[2]Wojskowa Akademia Techniczna, im. Jarosława Dąbrowskiego
ul. gen. Sylwestra Kaliskiego 2, 00-908 Warszawa

Streszczenie. Ośrodek Badań Dynamicznych Wojskowego Instytutu Technicznego Uzbrojenia (WITU) w Stalowej Woli od wielu lat prowadzi badania uzbrojenia zarówno na potrzeby polskiego przemysłu zbrojeniowego, Sił Zbrojnych Rzeczypospolitej Polskiej, jak i w celach naukowych. Jeden z obszarów tych badań dotyczy poznania wpływu różnych czynników (konstrukcyjnych, technologicznych, eksploatacyjnych itp.) na żywotność (trwałość) luf 120 mm armat Rh-120 L44, stanowiących uzbrojenie czołgów podstawowych Leopard 2A4 i Leopard 2A5. Czołgi te w liczbie 247 sztuk (142 – Leopard 2A4 i 105 – Leopard 2A5) są intensywnie eksploatowane przez polskie jednostki pancerne od 2002 r. W pracy przedstawiono wyniki niektórych badań zużycia przewodu lufy armaty Rh-120 L44, w wyniku strzelania amunicją produkcji polskiej i zagranicznej. Analizę wyników badań wykonano na podstawie „Dokumentacji Technicznej TDv18", która podaje ogólne kryteria niezdatności luf do dalszej eksploatacji (co jest równoważne z wycofaniem ich z użytku), tj. graniczną wartość zużycia materiału powłoki zabezpieczającej przewód lufy oraz liczbę strzałów, po przekroczeniu której zmęczenie materiału osiąga wartość graniczną. Ponadto sformułowano wnioski i kierunki dalszych prac w przedmiotowej dziedzinie.
Słowa kluczowe: eksploatacja uzbrojenia artyleryjskiego, badania właściwości balistycznych luf, uzbrojenie artyleryjskie