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Development of Ammunition with Unconventional Applications

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ABSTRACT
The aim of the work was to develop a composite consisting of tungsten powder and other metal powders, with the density close to that of lead (11.3 Mg/m^3), under laboratory conditions. This material should also meet the requirements for bullet cores. In order to check whether the material developed meets the set requirements, the scope of work included: material development, manufacturing cores of bullets from the produced material, manufacturing cartridges using the above-mentioned cores, conducting ballistics tests involving internal, external and final ballistics.

Keywords: ecological ammunition, ballistic studies, ammunition, material tests.

INTRODUCTION

One of the goals of these activities is to develop the so-called ecological materials that will eliminate lead as the basic material used in the cores of small caliber ammunition. Lead as a construction material (Durkee & Douglas, 2000) has been used for the manufacturing of weapon components from since the barrel firearm was invented. The choice of lead was mainly due to the ease of producing balls of the desired shapes and dimensions. With the invention of threaded barrels and the use of long-drawn bullets, lead became the basic material from which the bullets of small arms were made. In the cartridges with armor-piercing or other shells with steel cores, lead was used to make core jackets. Due to the low yield strength of lead, the resistance put up during the cutting of the barrel grooves in the shell of the projectile was small, which resulted in an increased lifespan of barrels.

Unfortunately, although technologically advantageous, lead (Mravic, 1995) (Mravic, 1995) is a material hazardous to people. Lead affects almost all organs and systems of the human body. Lead infiltrates the human body through inhalation or swallowing. For this reason, lead ranks second after the arsenic (before mercury), on the list of almost 300 of the most toxic substances threatening the human life and health (Middleton, 2000).

The Institute of Mechanics and Printing developed a technology for the production of construction materials that are substitutes for lead for use in the production of small arms cartridges. In these bullets, lead was replaced with a thermoplastic and thermosetting polymer composite with a filler in the form of tungsten powder (Schatt & Wieters, 1997) (Eroglu & Bayakara, 2000) (Politechnika Warszawska, Praca zbiorowa, maj 2010). The ammunition firing tests with 9 mm caliber bullets using the above-mentioned ecological materials showed that during the penetration of the simulated target model, these projectiles fragmented (Kaczorowski, et al., 2010). The cores of the projectile were smeared in the residual channel (Figure 1). In order to eliminate the aforementioned phenomenon, the work was undertaken to create a material free of these defects.

The purpose of the work was to develop a composite consisting of tungsten powder (Kaczorowski, et al., 2008) (Kaczorowski, et al., 2012) and other metal powders with the density close to the lead, i.e. $\rho = 11.3$ Mg/m^3 under laboratory conditions. This material should also meet the requirements for bullet cores.

MATERIAL

For the ecological ammunition (Politechnika Warszawska, Praca zbiorowa, maj 2010) to be able to replace the previously used material for cores developed within the framework of this work, a number of conditions must be met, namely:

- the projectile must be characterized by a flight path similar to that of a standard projectile of the same mass and dimensions, which means that the material density used in ecological bullets must be identical to the density of lead,
- the projectile must approximately behave in such a way that the shooter has the same impression as when shooting with standard ammunition,
- the projectile cannot penetrate or damage the steel plate normally used as a part of the collimator protection and cannot pose a ricochet threat,
- the projectile cannot be damaged or disintegrated while moving in the barrel of the weapon, as well as during the flight after leaving the barrel,
- the projectile cannot cause damage to the barrel,

The subject of the research involved 9×19 mm Parabellum (Figure 2) projectiles with cores made of W-Sn sintered material.

METHODS

The subject of the research involved 9×19 mm Parabellum projectiles with the cores made of W-Sn sintered material. The scope of work included:

- the production of the composites consisting of tungsten powder of various granularity and other powders,
- making bullet molds by pressing,
- testing the influence of the pressing pressure and the soaking time on the density of the composites obtained,
- making composite shapes with external contours corresponding to the shape of cores for 9mm Parabellum bullets,
- development of technology for the assembly of composite fittings for 9 mm pistol cartridges under laboratory conditions,
- manufacturing of 9 mm caliber bullets with a composite metal core for further ballistic tests.

On the basis of the previous experience and own research (Goroch & Gulbinowicz, 2017) for the production of composites for ecological ball cores, the following metal powders were selected:

- tungsten powder with a grain size of approx. 3.5 µm FSSS,
- spheroidal tungsten powder with a grain size of approx. 50 µm,
- tin powder,
- aluminum powder.

The compositions of powder blends: tungsten and aluminium (Goroch & Gulbinowicz, 2017) (Winiczenko, et al., 2017) as well as tungsten and tin were chosen in such a way that after forming the shape, they had the density corresponding

Fig. 1. A view of a pierced gelatine block with traces of blurred core remains in the residual canal.

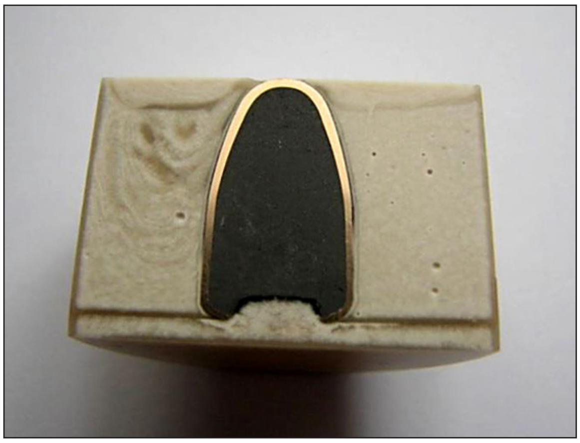

Fig. 2. Bullet with W-Sn core for cal. 9×19 mm Parabellum cartridge

to one of the PbSb1.5 alloy, taking into account their porosity. Forming of the fittings took place by cold pressing in the form of 8 mm diameter of. The diameter of the mold corresponded to the inner diameter of the 9 mm Parabellum bullet. The mixtures of powders (Eroglu & Bayakara, 2000) (Schatt & Wieters, 1997) differing in their composition are marked with the following indices: A, B and C (Table 1)

TEST RESULTS

Density

The results of the tests on the influence of the pressing pressure on the density of fittings made of various sinters are given in Tables 2–4, together with the information on the behavior of the fittings after the load. In the case of mixtures A and B, the theoretical density of the shapes (without porosity) was $\rho = 11.96$ Mg/m^3, while the shapes of the mixture C$\rho = 12.66$ Mg/m^3.

On the basis of the results presented in the tables, it was found that the results turned out to be promising only for fittings made of the mixture C, provided that the pressing pressure would be in the range of $p = 100 \div 200$ MPa. For this reason, only this material has been subjected to the strength tests.

Test results on a strength machine

The strength tests were carried out on a batch of molded parts of the composition, which were made by pressing using three different pressure values: p = 100, 200 and 300 MPa. The fittings thus made were subjected to compression on a strength machine. The diagram in Figure 3 presents the values of compression forces as a function of traverse displacement.

On the basis of the obtained results, it was found that the shapes produced at the pressures: p = 100 MPa and p = 200 MPa have the smallest maximum compressive strength. Due to the fact that the density of the fittings obtained for these pressure values is slightly lower than the density of the lead alloy $\rho = 11.3$ Mg/m^3, an attempt was made to compact the fittings. For this purpose (Jackowski, 2004), attempts were made to heat the moldings under pressure p = 100 and p = 200 MPa. The fittings were heated for 1 hour

Table 1. Determination and chemical composition of powder blends

Mix symbol	Share of components [% by mass]			Comments
	Tungsten	Aluminum	Tin	
A	90	10	-	Tungsten powder with spheroidal geometry
B	70	-	30	Tungsten powder with a grain size of 3.5 FSSS
C	70	-	30	Tungsten powder with spheroidal geometry and average grain size of 50 μm

Table 2. Effect of pressing pressure on the density of sinter A

Sample No.	Pressing Pressure	Sample Weight	Sample Volume	Sample density	Comments
	[MPa]	[g]	[cm^3]	[g/cm^3]	
1	200	7.05	-	-	The sample spilled out of the mold
2	400	7.30	0.72	9.73	The sample crumbles after removal from the mold

Table 3. Effect of pressing pressure on the density of sinter B

Sample No.	Pressing Pressure	Sample Weight	Sample Volume	Sample density	Comments
	[MPa]	[g]	[cm^3]	[g/cm^3]	
1	100	-	-	-	The sample spilled out of the mold
2	226	5.83	0.62	9.49	The surface of the mold from the bottom of the stationary punch is fragile
3	200	4.59	0.485	9.46	The form is placed on a hard rubber washer
4	400	6.98	0.655	10.7	The form is placed on a hard rubber washer
5	100	6.61	0.75	8.8	The form is placed on a hard rubber washer

Table 4. The effect of pressing pressure on the density of sinter C

Sample No.	Pressing Pressure	Sample Weight	Sample Volume	Sample density
	[MPa]	[g]	[cm³]	[g/cm³]
1	100	6.60	0.62	10.71
		6.68	0.61	10.95
		6.68	0.63	10.60
2	200	6.67	0.58	11.50
		6.66	0.565	11.78
		6.63	0.56	11.80
3	300	6.66	0.54	12.30

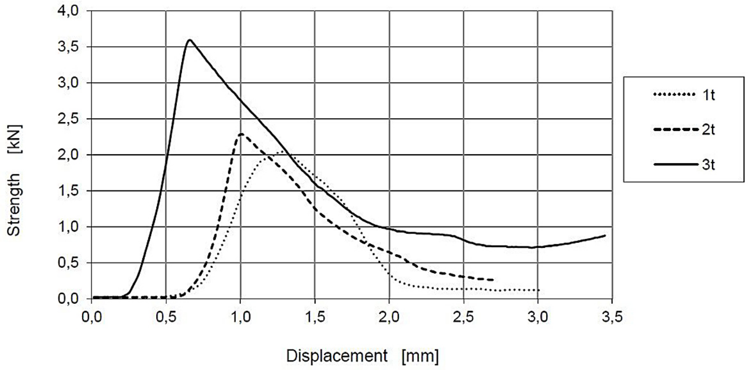

Figure 3. Graphs of compression forces as a function of traverse displacement for shapes made of the W-Sn powder produced at different compression pressures: 1t=100 MPa, 2t=200 MPa, 3t=300 MPa

at T = 220°C and T = 250°C. In the case of annealing temperature T = 220°C, there was no change in the density of the fittings. On the other hand, heating at T = 250°C led to the condensation of tin in the form of small beads on their surface, which can be explained by the lack of wetting of tungsten by tin at this temperature (Fig. 4). The results of tests of heated fittings during the compression test on a strength machine are shown in Figure 5.

Research mounting fittings

The formed fittings were subjected to the process of connection with the shell of the projectile, i.e. merge. A properly connected shape constituting the core of the projectile must correspond to the inner contour of the shell with its external contour. In order to check whether the shape of the fitting is not damaged during the consolidation process, and to determine the range of forces necessary for correct assembly, it was necessary to carry out the check tests. Due to the fact that the former cylindrical shape was incorrectly pressed into the shell of the projectile, in the further stage the molds were made into a core in the form of a cylinder rounded in its lower part (Fig. 6).

On the basis of the conducted tests, it was found that in order to ensure the correct filling

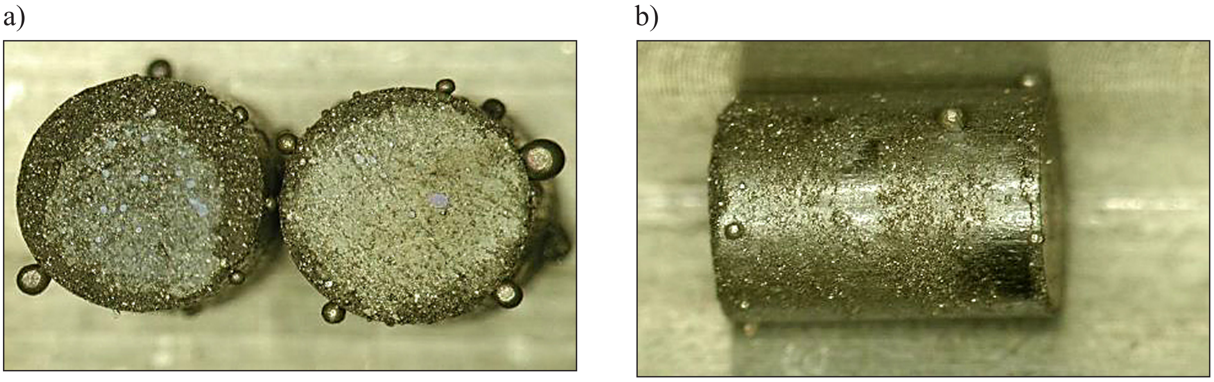
a)
b)

Fig. 4. Fittings with visible tin condensation on the surface after heating for one hour at T = 250°C

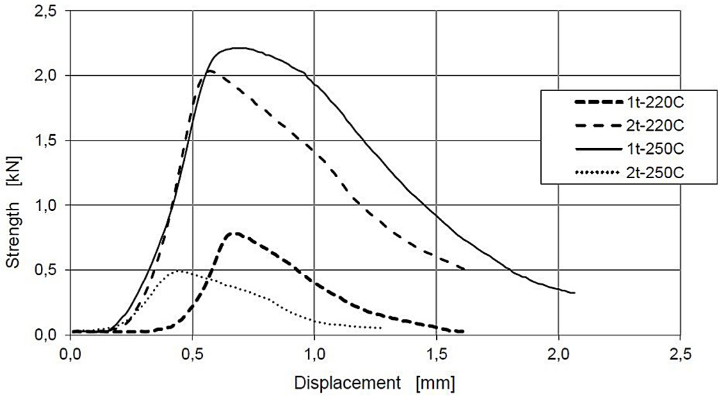

Fig. 5. Plots of compressive forces as a function of traverse displacement for shapes from W-Sn powder after pressing under pressure p = 100 MPa, and p = 200 MPa, at temperature T = 220°C and T = 250°C

process of the shell by the core, the values of the consolidation forces should be:

- strength of the molding of the fitting to the jacket – from 4000 N to 5000 N,
- force bending the coat – about 4000 N,
- compression force – 5000 N.

Laboratory ballistic tests

In order to check the behavior of cartridges with ecological cores during the shot on the flight path as well as during the penetration of the target, ballistic tests were carried out in the shooting tunnel. During the tests, the following were checked:

- if the projectile does not damage the barrel,
- if the projectile is not damaged or broken during the movement in the barrel of the weapon,
- if the projectile does not create a ricochet threat,
- stabilization of the projectile on the flight path,
- the behavior of the projectile during the penetration of the simulated model of the human body.

The research was carried out on a test stand with the construction scheme shown in Figure 8. The stabilization of the projectile flight path is determined on the basis of observation and evaluation of the shape of the control board bullet holes. All shots were circular, which indicates the stabilization of the projectile on the flight path.

In order to investigate whether the projectile is not damaged during the movement in the barrel, it has been checked for traces of small holes in the control carton made by the fragments of the core material being tested. On the basis of the visual inspection of control cartons, there were minimal traces of punctures on the carton.

The behavior of the projectile during the penetration of the human body model was studied on a simulator. The blocks made of a mixture of

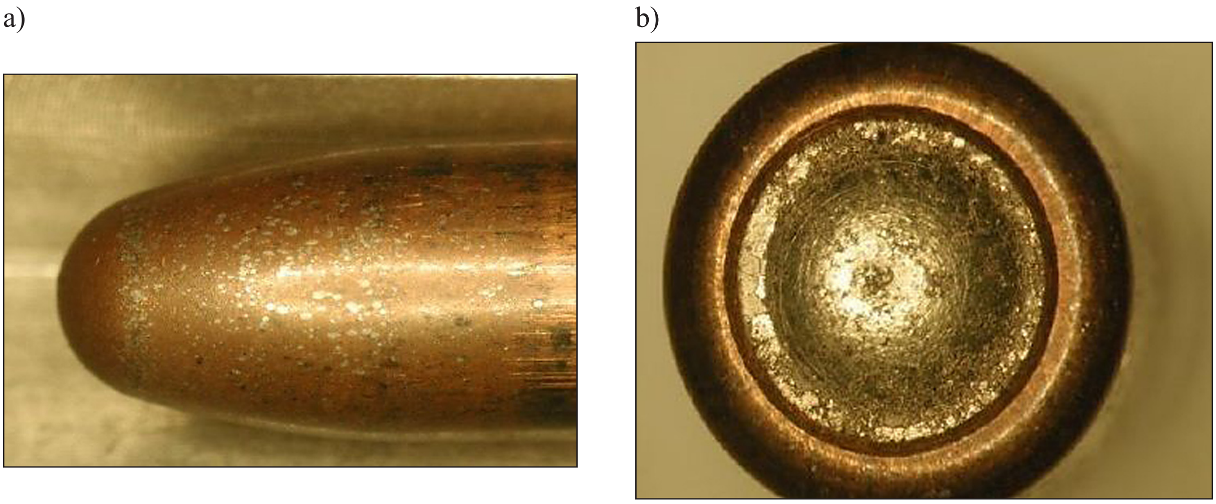

Fig. 6. View of the projectile while ensuring correct consolidation forces: a –side and b – rear

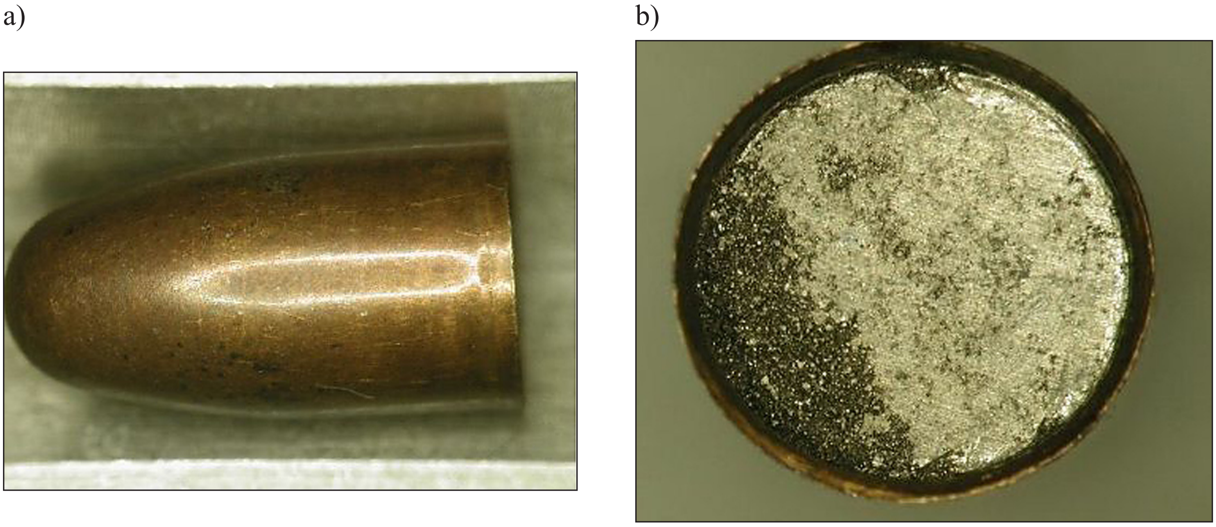

Fig. 7. View of the projectile with too high pressing force of the fitting: a –side and b – rear

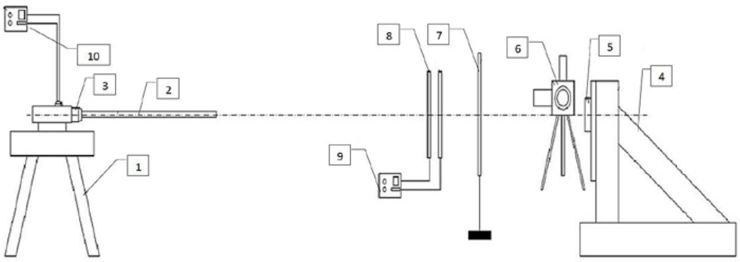

Fig. 8. Construction scheme of the test stand: 1 – base, 2 – throwing system, 3 – pressure sensor, 4 – capture system, 5 – target simulator, 6 – digital camera PHOTRON SA5RV, 7 – control carton, 8 – speed gates, 9 – speed recorder, 10 – pressure recorder

water and gelatin with a 20% content of Blom pork gelatine were used as a target simulator. The gelatin blocks of the above-mentioned concentration simulate the human body parameters, provided that the block temperature during ballistic tests equals 10°C. A mixture of water with 10% gelatin may also be used, but the temperature of the measuring block must then be kept at 4°C. Obtaining such measurement conditions in the ballistic laboratory of the Institute of Mechanics and Printing was impossible.

The study of the projectile behavior while penetrating the body model was carried out for two configurations:

- shooting at an uncovered simulator,
- shooting to a shielded simulator.
- The simulator shell used ballistic inserts used as shields in protective vests. During the tests, the number of cover layers was changed.

Ballistic results of the simulator of the uncovered target

The tests were carried out on an uncovered gelatin block measuring 13×13×39 cm (Figs. 9, 10).

Figure 11 presents a 9 mm bullet with a lead-free core after penetration of a bare gelatin

Fig. 9. A view of uncovered gelatin sheath on the test bench before the shot

Fig. 10. Photograph of uncovered gelatin sheath during penetration 9 mm bullet with lead-free core

sheath. There is a visible lack of damage to the ogive of the projectile, projectile mass q = 7.924 g, projectile impact speed V_u = 336.7 m/s.

The results of ballistic tests of a covered target simulator

The tests were carried out on a sheathed gelatin block measuring 13×13×39 cm, and ballistic inserts used in protective vests were used as covers. During the tests, the number of cover layers was changed. For comparison, the phenomena occurring during the piercing of the firing target were carried using the ammunition with both conventional and unleaded bullets. In the research, a 9×19 mm Parabellum cartridge produced by ZM MESKO in Skarżysko Kamienna was used as the traditional ammunition.

Fig. 11. An image of a control carton with a bullet hole

Fig. 13. Image of a projectile with a traditional core after piercing a 6-layer ballistic obstacle

Study of shooting with traditional projectile

The sample results of tests by shooting a shielded target model with a traditional projectile are shown in Figure 12. In the picture, a visible projectile stuck in the bullet holes. Figure 13 shows a projectile after piercing a 6-layer ballistic obstacle. Significant deformation (mushrooming) of the front of the projectile is visible.

Study of shooting with unleaded core

The research on the behavior of the projectile after piercing is shown in Figures 14, 15, 16. In order to investigate how the projectile behaves with the variable thickness of the ballistic shield, the tests during which the number of protective layers was changed were carried out. The fired bullets were recovered after passing through a shielded gelatin block. On the basis of the visual inspection of the fired projectiles, it should be stated that the deformations of the front part of the ogive of lead-free bullets are smaller than in the traditional projectiles.

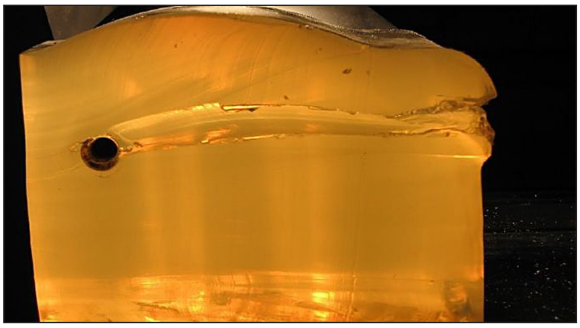

Fig. 12. A picture of a cut gelatine block with a visible residual canal

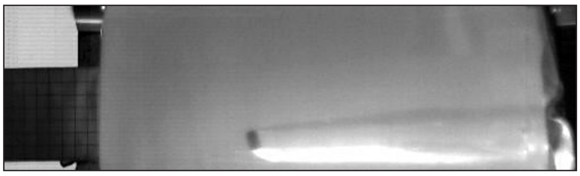

Fig. 14. Picture of a gelatine sheath covered with a 6-layer cover during penetration through a 9 mm unleaded core

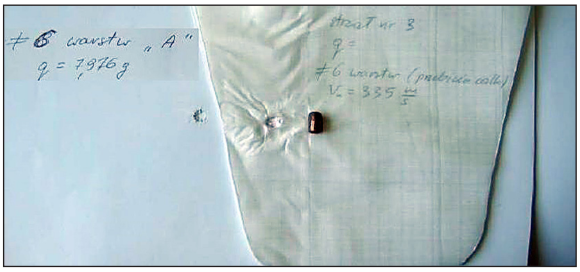

Fig. 15. Photo of the pierced 6-layer ballistic shield, lead-free bullet and control carton with bullet holes– bullet weight q = 7.924 g, – projectile impact speed Vu = 335.1 m/s

CONCLUSIONS

On the basis of the results obtained as part of the implementation of this work, the following conclusions were drawn:

- it is possible to obtain the material which is a replacement for lead in bullets
- cal. 9 mm projectiles with a lead-free core made of the material developed do not cause damage to the barrel,
- cal. 9 mm bullets with lead-free core are not damaged or broken during the movement in the barrel of the weapon,
- the preservation of projectiles with lead-free core is approximately the same as when shooting with standard ammunition,
- when firing cal. 9 mm bullets with lead-free core, there is no ricochet threat,
- the ballistic parameters of 9 mm ammunition with unleaded core are similar to the parameters of the same caliber ammunition with conventional projectiles

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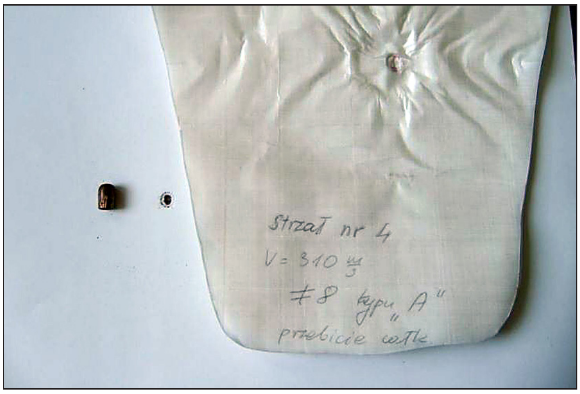

Fig. 16. A photo of a lead-free projectile, shot in a control carton and a pierced 8-layer ballistic shield. – mass of the projectile q = 8,12 g – impact velocity of the projectile Vu = 310 m/s