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BALLISTIC TESTING OF ADDITIONAL ARMOUR DEMONSTRATORS

Abstract. The article presents the methodology and results of armour ballistic resistance testing. The armour was designed and manufactured by the Institute of Non-ferrous Metals, Light Metals Division (IMN OML) in cooperation with LUBAWA S.A. Additional armour was made of multi-layer materials, including special ceramics and light metals. The method of creating armour demonstrators for Armstal armoured steel 6 mm, 8 mm and 10 mm thick armour is presented. Description and possible applications of object demonstrator designed and manufactured by "OBRUM" sp. z o.o are also given. All of the armour and the object demonstrators were designed to be tested in accordance with STANAG 4569 and AEP 55 standards. Ballistic tests of the armour demonstrators showed positive results according to standard requirements for 8 out of 9 demonstrators. The research results show that the object demonstrator is suitable for conducting a wide range of tests in accordance with the standards.

Keywords: passive armour, ballistic resistance, ballistic testing.

1. INTRODUCTION

Research and development work on new generations of additional ballistic shields protecting against 14.5 mm antitank missiles are mainly aimed at the application thereof in military vehicles (personnel and cargo transporters), armoured personnel carriers, tracked platforms, combat helicopters, patrol boats, etc. One of the important goals is to minimize the weight and thickness of the armour. This has a major impact on the operating range, fuel consumption, arms and ammunition payload. The weight per square metre and the thickness of the armour are critical parameters in the case of lightweight vehicles and combat helicopters. The use of an armour resistant to 14.5 mm calibre antitank missiles is becoming a standard for many types of land vehicles.

The materials used in sandwich (multilayer) lightweight ballistic shields include ceramics, plastics, fibre reinforced epoxy resins. The layer that has the decisive effect on the protective capacity is the ceramic layer [1]. The type and thickness of the ceramic material have a significant effect on the total weight of the armour [2]. The shape of the ceramics is also quite significant. They may take on the following forms: small- or large-size, monolithic or graded cuboid plates arranged in one or more layers, balls or cylinders arranged in one or more layers, cones or other shapes [2, 3]. There is a continuous search for new, lighter materials that would permit the use of thinner ceramics and thereby reduce the weight of ballistic covers. Such materials, applicable in the construction of sandwich armours, include, for instance, high strength light metal alloys, which are the subject of research conducted by the Institute of Non-ferrous Metals [4, 5].

The designers of additional armour must take into consideration the existing structure of the object on which the armour is to be installed. This causes technical problems of the armour fastening arrangement. Note that, for instance, the kinetic energy of an 14.5 mm AP projectile is about 31 kJ when the muzzle velocity is 1000 m/s. This is about ten times more than the energy of a 7.62 mm B-32 projectile. The impact of the projectile causes armour deformation and can upset

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the structure of the hull. For this reason the design of the additional armour fastening members is one of the major problems that require solving. The use of ballistic shields resistant to higher calibre antitank projectiles requires modification and strengthening of the armour fastening systems. Therefore the development of an appropriate fastening system for modular armour is the second most important issue after the development of the design and structure of the armour itself. The developed system of additional armour and its dedicated fastening system must be tested under operational conditions, as close to the real ones as possible. If there is no specified application for the devised solution, then conditions for testing demonstrators should be provided by designing a test facility and developing procedures for verifying compliance with applicable standards [6, 7].

The aim of the work was to develop a concept and fabricate a system of additional modular armour comprising ballistic shields and fastening elements therefor in an arrangement that would enable fast dismantling, replacement and maintenance. A system of ballistic resistance of level II, II and IV according to STANAG 4569 would be designed for installation on armoured personnel carriers and tracked platforms. The project included construction of a technology demonstrator and testing its resistance to projectile impact under field conditions. This paper presents the manner of setting up and carrying out ballistic resistance testing of the technology demonstrator in accordance with STANAG 4569.

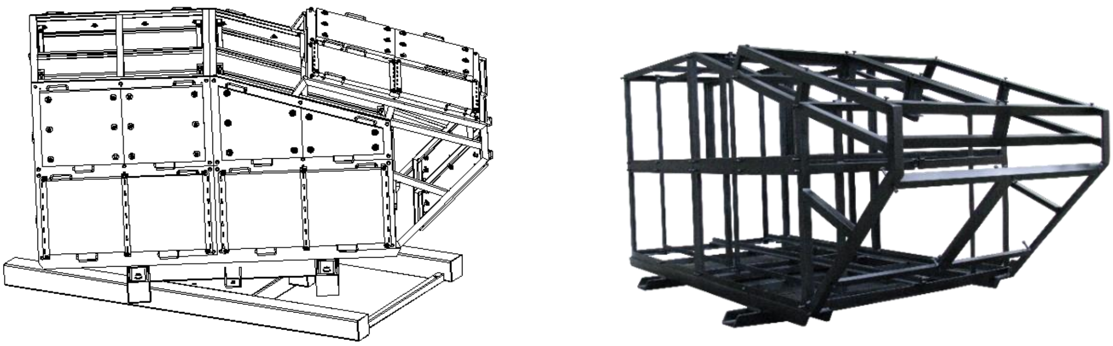
2. MATERIALS AND RESEARCH METHODOLOGY

Additional multilayer armour was fabricated by combining different materials, where each of the materials forms one of the layers. Materials were bonded using thermosetting or chemically cured adhesives, epoxy resins, elastomers. Some layers of these multilayer materials were applied by laminating, spraying or soaking. Such technology forms multilayer systems of a "sandwich" type. Armour was made using such materials as: special ceramics based on Al_2O_3 and SiC, plastics, glass or aramid fabrics, light metals, elastomers. In the materials produced each layer fulfils a strictly specified role in stopping an antitank projectile and absorbing its kinetic energy. Properly selected sequence of layers, their thickness and bonding technology determine the ballistic resistance of the multilayer material and, in consequence, of the whole armour. Multilayer materials based on high-tech materials and advanced manufacturing technologies create opportunities for an easy configuration of their structure to obtain the required ballistic resistance. In short, to raise or lower the ballistic resistance of a multilayer material, either the configuration of the materials must be modified or the thickness of individual layers must be changed. This creates the opportunity to easily adjust a given variant of the multilayer material to the desired level of ballistic resistance while maintaining optimum armour parameters, that is its minimum thickness and weight per 1 m^2.

The armour modules (Fig. 1) were constructed at LUBAWA S.A. facility in cooperation with the Institute of Non-ferrous Materials according to a jointly developed technology [8]. The following pieces of armour were fabricated: squares 6 to 12 mm thick - symbol D.XI.4, D.XI.5, D.XI.6 designed for level 2 testing (according to STANAG 4569), trapezoids 15 to 22 mm thick - symbol D.XI.7, D.XI.8, D.XI.9 designed for level 3 testing (STANAG 4569), and squares 25 to 30 mm thick - symbol D.XI.10, D.XI.11, D.XI.12 for level 4 testing (STANAG 4569).

Fig. 1. Examples of additional armour modules

The assembly system for the various variants of additional armour modules was developed by OBRUM. The object demonstrator structure, also developed by OBRUM [7] (Fig. 2b) was used for fastening thereto of the armour demonstrators and for carrying out ballistic resistance tests. The object demonstrator was adapted to suit all variants of the additional armour to be tested.



a) view of the demonstrator b) body supporting structure

Fig. 2. Object demonstrator [7]

The design of the object demonstrator reflected the structure of a conventional armoured personnel carrier. The frame structure of the object demonstrator enabled installation of armour modules of square or trapezoid shape. The demonstrator consisted of a base with a turntable and of a body with partitions/backstops. Additionally, a witness plate made of aluminium alloy was installed inside the object demonstrator. The turntable enabled firing at the side plate of the object at the angles of 90°, 30° and 60° and optimized the course of testing by rotating the object by 180° to enable firing at the other side of the object without having to reposition the test instruments.

Multilayer armour plates (Fig. 1) were attached to 6, 8 or 10 mm thick Armstal 500 steel plates which served as the basic armour. For level 3 and 4 testing, spall liner plates of polyethylene were attached on the inner side of the basic armour. Such protective setup constituted an additional, passive, modular armour (armour demonstrator Fig. 3) for the object demonstrator.

The manner of installing armour demonstrators on the object demonstrator is illustrated in Fig. 4.

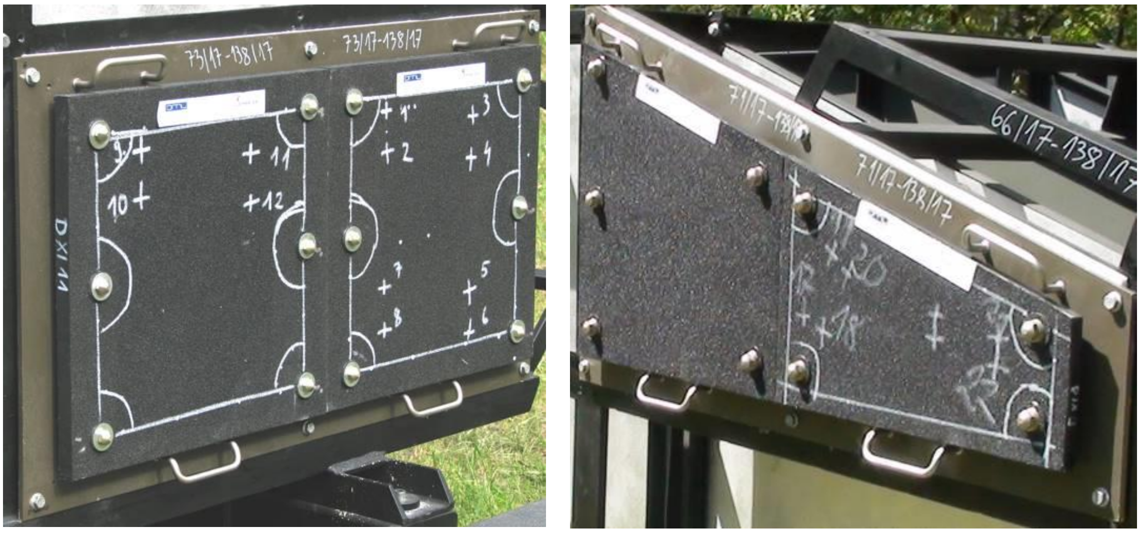


Fig. 3. Examples of armour demonstrators for testing

Fig. 4. Object for testing with demonstrators

Ballistic tests were carried out in the Accredited Laboratory for Testing Firing Arms and Protective Shields at the Military Institute of Armament Technology in Zielonka. The following procedures were applied during the tests: testing of ballistic resistance of samples and radar measurement of projectile velocity. The scope of tests and the methodology thereof were set up in such manner as to enable application with the Certification Centre of the Military Institute of Armament Technology for a Certificate of Conformity to confirm compliance of the IMN/LUBAWA multilayer demonstrators with the STANAG 4569 standard (Protection Levels For Occupants Of Armoured Vehicles). Level 2, 3, 4 tests were performed using the following ammunition: 7.62x39 mm BZ, 7.62x5 mm Nammo AP8, and 14.5x114 mm B32, and Annex B to AEP 55 Volume 1 – Procedures For Evaluating The Protection Level Of Armoured Vehicles, Multi-Hit Procedure.

The complete acceptance process used to establish the Protection Level of a defined vehicular armour system consists of four sequential phases:

- Phase 1. Test plan definition
- Phase 2. Main Areas ballistic evaluation
- Phase 3. Structural Weak Areas ballistic evaluation
- Phase 4. Vulnerable Area evaluation and protection assessment.

Testing of the presented demonstrators and with the use of the object demonstrator can be carried out for both Phase 2 as well as Phase 3. Phase 2 comprised testing of main areas (MA) and localized weak areas (LWA), the example of which are modules made of non-homogenous materials, e.g. ceramic plates. Phase 3 includes testing of structural weak areas (SWA), for instance: edges of modules, gaps in between or fixing elements. Excluded zones (EZ) (Fig. 3) were specified on the modules during the preparation thereof for testing. These included areas around individual armour modules and around fastening system elements. The EZ initially specified for testing within MA should undergo tests in Phase 3 to validate if that zone is ballistically resistant or if it is a vulnerable area (VA).

According to STANAG 4569 and Annex to AEP 55, for KE threats Levels 1 - 3 the minimum number of rounds is normally set to 22, and for Level 4 it is 12. In order to determine the required protection capability as defined in the STANAG for KE threats, the multi-hit testing system described in Annex B to AEP 55 should be applied.

3. RESULTS OF BALLISTIC TESTING OF ARMOUR DEMONSTRATORS

Of the nine tested additional armour variants installed on basic steel armour, thickness 6 mm, 8 mm and 10 mm, eight proved successful and compliant with the requirements of STANAG 4569 for Level 2, 3 and 4 (these were granted Certificates of Conformity). Only in the case of D.IX.9 one of the projectiles penetrated the demonstrator completely. The number of rounds for this variant was increased to 24. 23 rounds were stopped (22 shots is the requirement in the multi-hit mode). However, according to the standard one complete penetration means a failed test. Figs. 5 to 8 show examples of armour demonstrators that have undergone ballistic testing.

Table 1 lists the tested armour demonstrators along with their geometric dimensions and test results.

Table 1. List of test results for IMN/LUBAWA armour demonstrators

No.	Code	Armour demonstrator dimensions (mm)	Steel armour (mm)	Spall-liner	Weight 1m^2	Level STANAG 4569	Test result	Certificate
11	**D.XI.4**	600x1100	6	---	22	2	+	YES
2	**D.XI.5**	600x1100	8	---	19.4		+	YES
3	**D.XI.6**	600x1100	10	---	17.5		+	YES
4	**D.XI.7**	Trapezoid 256/600x1100	6	YES	45	3	+	YES
5	**D.XI.8**	Trapezoid 256/600x1100	8	YES	35		+	YES
6	**D.XI.9**	600x1100	10	YES	34		+/-	NO
7	**D.XI.10**	600x1100	6	YES	77	4	+	YES
8	**D.XI.11**	600x1100	8	YES	68		+	YES
9	**D.XI.12**	600x1100	10	YES	61		+	YES

Fig. 5. Armour demonstrator DXI8 (front)

Fig. 6. Armour demonstrator DXI8 (back - 8 mm plate)

Fig. 7. Armour demonstrator DXI11 (front)

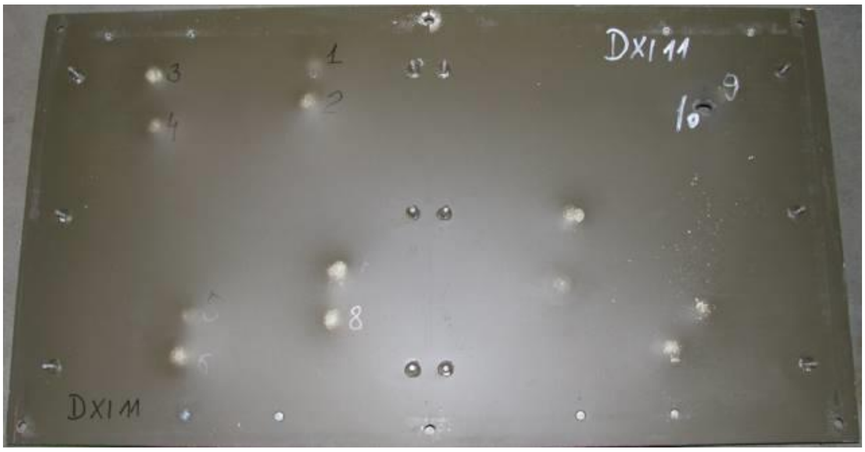


Fig. 8. Armour demonstrator DXI11 (back - 8 mm plate)

The testing scheme, that is the arrangement of spots on the demonstrators where shot impacts were made, was not a random one, but it followed from the requirements of STANAG 4569 and AEP55. Despite using stable support stands, on which ballistic barrels were installed, and despite using laser sights, there were misses. Such was the case, for instance, with armour demonstrator D.XI.11. Photographs (Figs. 7 and 8) show that round no. 10 hit the same spot as previous round no. 9. In such case of complete penetration resulting from a hit not compliant with the standard and not from the defect of the tested module, that pair of shots is not taken into consideration in the assessment process. A new hit location is then specified. This is the reason for additional hits, nos. 13 and 14, appearing on demonstrator D.IX.11. Velocity measurement is performed for each projectile during the tests and the value measured is verified for compliance with standard requirements. When the measured projectile velocity is outside of the range specified in the standard for the given ammunition type, that is when it is too low or too high, then the ballistic test should be repeated in other location of the module, as was the case with improper (not compliant with the standard) hit.

Fig. 9 shows an example of an armour demonstrator on which the excluded zone (EZ) was tested (Phase 3). This demonstrator was subjected to ballistic testing for Level 4 of STANAG 4569. The edge of the module (hit no. 7) and the module fixing element (hit no. 8) were intentionally hit. In both cases the test was passed, the projectiles were stopped, even though the hit locations were within potentially weaker areas.

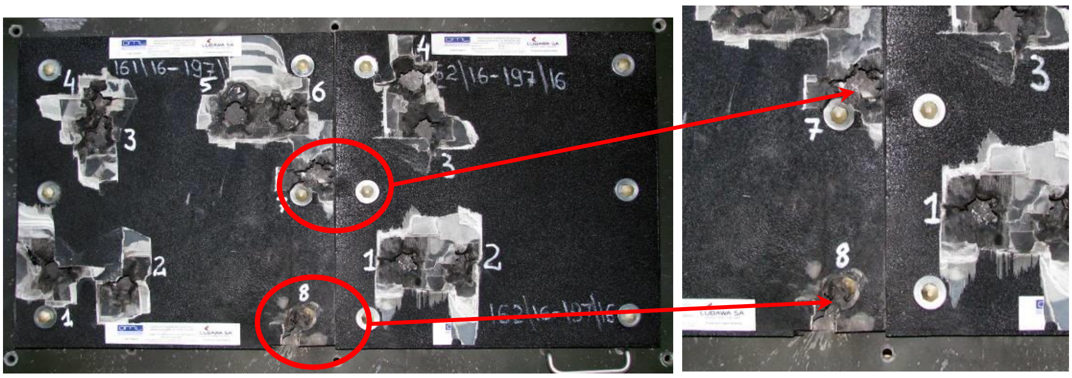


Fig. 9. Example of an armour demonstrator where, in addition to the main area, the excluded zone was also tested (nos. 7 and 8 marked red)

4. SUMMARY

In the course of development work aimed at determining the ballistic resistance of additional armour modules, where the main areas and, within a reduced scope, the excluded zones were tested, the tested modules passed the tests. The results show that the fabricated additional armour modules have a very homogeneous, rigid structure (as for a multi-layer material with elements made of special ceramics). The proposed design of armour demonstrators (comprising two armour modules installed adjacent to each other) and object demonstrator enables testing of additional armour within a wide scope for Phases 2 and 3 in accordance with STANAG 4569 and AEP55.

5. CONCLUSIONS

1. Ballistic resistance tests were carried out according to STANAG 4569 and AEP55 of 9 variants of IMN/Lubawa additional armour demonstrators installed on an object demonstrator.
2. Eight variants of additional armour met the requirements of STANAG 4569. One of the modules, despite having stopped the required number of shots, failed the test because of one perforation.
3. It was shown that the object demonstrator designed and fabricated by OBRUM enables performing ballistic tests of additional armour according to STANAG 4569 and AEP55.
4. The development work conducted as part of the project enabled attaining technology readiness level 7 for the additional armour.

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