A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 53 2008 Issue 1

L. STARCZEWSKI*

MICROSTRUCTURE OF A COMPOSITE PADDED LAYER OF METAL POWDERS AND ITS RESISTANCE TO PENETRATION WITH A HARD CORE BULLET

MIKROSTRUKTURA KOMPOZYTOWEJ WARSTWY NAPAWANEJ Z PROSZKÓW METALI I JEJ ODPORNOŚĆ NA PRZEBICIE POCISKIEM Z TWARDYM RDZENIEM

The article presents the following thesis: an armour material with hardness gradient shall successfully withstand the impact of a bullet with a hard core (65HRC) if the hardness of the surface layer is higher than the hardness of the bullet core and the layer is deposited on a soft substrate. A ballistic experiment was conducted to examine the ability of a hard (72HRC) composite padded layer – made of metal powders deposited by the plasma technique on soft steel (180HB) – to withstand the impact of bullets with a hard core. The microstructure of the padding weld was identified and its chemical composition was analysed. The examined material system with hardness gradient was found to be able to withstand successfully the impact of bullets with a hard core, while core defragmentation was the dominant mechanism. The examination of microstructure demonstrated an interrelation between the mechanism and the structure of the padded material.

Keywords: metal composites, padding, armour, bullets, armour piercing, hard core, hardness gradient, padding microstructure, microanalysis

W artykule postawiono tezę, że materiał na pancerz o właściwościach gradientu twardości skutecznie zatrzyma pocisk z twardym rdzeniem (65HRC), jeżeli twardość warstwy powierzchniowej będzie powyżej twardości rdzenia pocisku i będzie utworzona na miękkim podłożu. W eksperymencie balistycznym zbadano zdolność twardej (72HRC) kompozytowej warstwy napawanej, utworzonej z proszków metali techniką plazmową na miękkiej stali (180HB), do zatrzymania pocisków z twardym rdzeniem. Przeprowadzono identyfikację mikrostruktury i analizę składu chemicznego napoiny. Badany układ materiałowy o gradiencie twardości, potwierdził swoją skuteczność w zatrzymaniu pocisków. W procesie tym dominującym mechanizmem jest fragmentacja twardego rdzenia. Badania mikrostruktury ujawniły związek pomiędzy tym mechanizmem a budową strukturalna napawanego materiału.

1. Introduction

The search for efficient protection of military vehicles and equipment against the impact of armour-piercing bullets (AP) has lead to the development of unconventional armour plates. The design of armour resistant to AP-type bullets takes into account two basic impact mechanisms, which occur when a hard bullet core (hardness exceeding 65 HRC) pierces an armour material [1].

One of the mechanisms assumes, that a bullet penetrates into an armour, while simultaneously eroding the materials in contact [6]. The energy of the bullet dissipates into the work of mechanical deformation of armour materials and the change of plasticity of the bullet core and the armour material, which is caused by high temperature at the spot of impact, and into the work of friction forces, caused by movement of the bullet inside the armour material [5][7]. Assuming this to be the leading mechanism of piercing, one can state, that the protective efficiency of an armour is a function of the armour thickness and the rheological properties of its material. This results in the design of armour plates of considerable weight. The mechanism is dominant in armours, the hardness of which is lower than the hardness of a bullet core.

The second mechanism appears in armours characterized by hardness, which exceeds the hardness of bullet cores, and consisting in the decomposition of a hard bullet core into smaller fragments (the so-called "defragmentation"), resulting from the collision with a

* MILITARY INSTITUTE OF ARMOUR & AUTOMOTIVE TECHNOLOGY, UNIVERSITY OF WARMIAN AND MAZURIAN, 05-070 SULEJÓWEK, 1 OKUNIEWSKA STR., POLAND

harder material. The energy of impact is dissipated into the energy of particular fragments, which act on a larger area and penetrated the armour, which results in elastic and plastic deformations in the armour material. In this case, the armour design is aimed at producing a sufficiently hard layer – preferably much harder than the bullet core [8] – on a soft substrate. The design based on the assumption of this mechanism has lead to the development of unconventional composite materials, characterized additionally by a considerably smaller weight, compared to steel armour plates [2][3]. The introduction of multi-layered systems, consisting of ceramic, polymeric and metal components, reduced the interest in armour steels, as composite armours are characterized by a better mass efficiency Em>3(for steel Em = 1).

Numerous publications indicate, that this advantageous index can be achieved in armours with gradient mechanical properties. It means, that particular layers of the entire armour structure are characterized by different mechanical properties and are made of different physical materials [4]. In spite of high mass efficiency, multi-layered composite armours have their characteristic drawbacks as well. One can mention the following: complex methods of joining particular layers, difficult production technology, reduced compliance with the criterion of multiple impact. Moreover, it often happens, that one hit with a bullet produces so wide destruction zone, that the armour can no longer protect effectively against another hit.

The development of the technology of composites based on powdered metals resulted in a revival of interest in steels. Taking advantage of the positive effects of gradient properties of composite armours, the research focused on the production of a layer characterized by high hardness on a relatively soft steel substrate, which produces a gradient of hardness and plastic properties in a single material layer [9].

2. Goal, scope, object and methods of research

The work was aimed at examining the microstructure of a hard composite layer made of metal powders, padded on soft steel sheet metal, and at demonstrating the impact of the layer on the dissipation of the energy of bullet impact.

The practical goal of the research consisted in demonstrating, that the examined structure with gradient hardness is able to efficiently withhold the impact of an armour-piercing bullet. The research used an 11 mm thick sample made of XPWM steel, with a 5 mm thick padded layer, deposited by the plasma technique. The padded layer consisted of padding welds, about 35 mm wide, deposited to overlap with substrate weld penetration (fig. 6). The layer was made of metal powders with the granulation of 60-200 μm and the following general chemical composition: Fe, Cr, V, Mo, Nb, B.

The hardness of the obtained layer reached 72HRC, while the hardness of the substrate steel sheet metal reached 180 HB (average values obtained on the basis of 5 measurements). The examination of the microstructure and the analysis of the chemical composition in micro-areas were carried out by means of a scanning microscope, equipped with EDAX analyzing module. The examination of the protective efficiency were carried out with two types of armour-piercing bullets, namely: 7.62×39 AP BZ and 7.62×51 AP. The ammunition used in tests differs considerably as to the bullet impact energy, which amounts to the following values: E_{BZ} ~2,1 KJ and E_{AP} ~3,5 KJ, respectively. In both ammunition types, the bullet core is made of steel and its hardness amounts to 65÷67 HRC.

3. Examination results

Examination of the microstructure with the micro-analysis of the chemical composition.

The microstructure analysis accompanied with microanalysis were carried out on a sample taken from the object of research at the polished section perpendicular to the direction of overlapping of padding welds. The observed results are presented in Fig. 1, 2, 3, 4, 5.

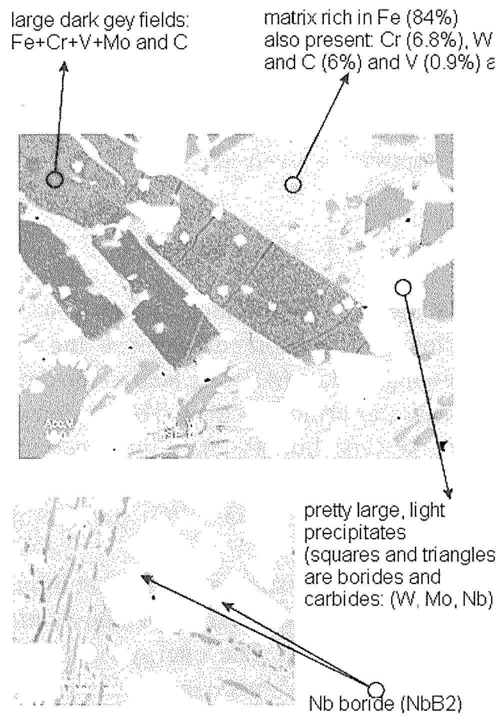

Fig. 1. Overview of the padded layer. The image shows the phases characteristic for the structure, where the microanalysis of the chemical composition was carried out

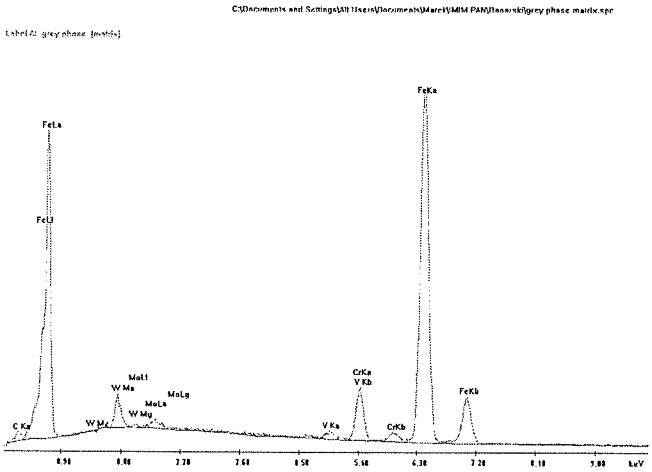

Fig. 2. The results of the microanalysis of the "grey" phase – the matrix

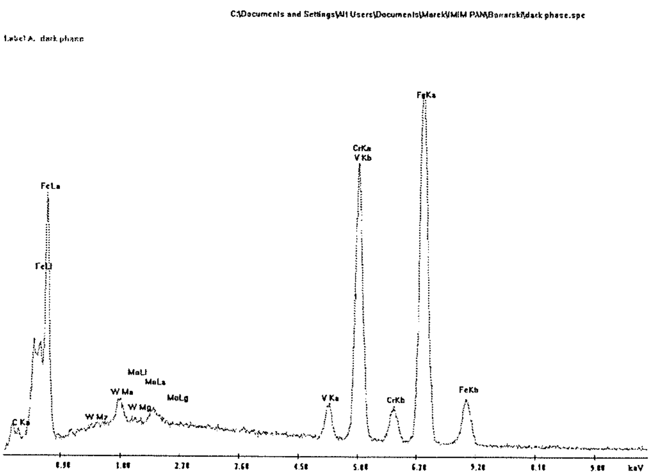

Fig. 3. The results of the microanalysis of the "dark grey" phase

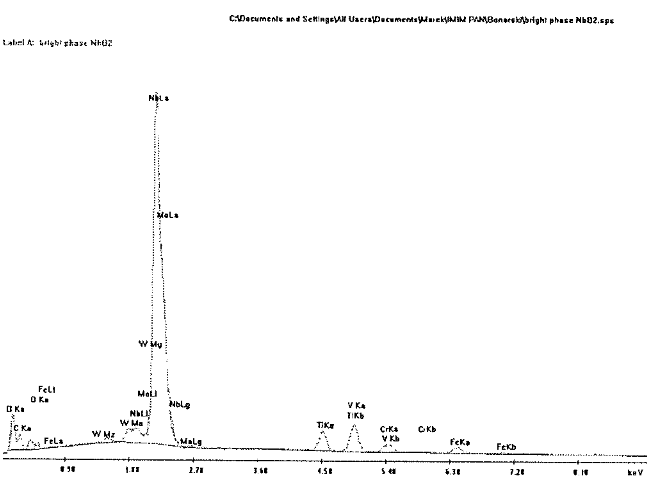

Fig. 4. The microanalysis of square- and triangle-shaped precipitates in the "white" phase

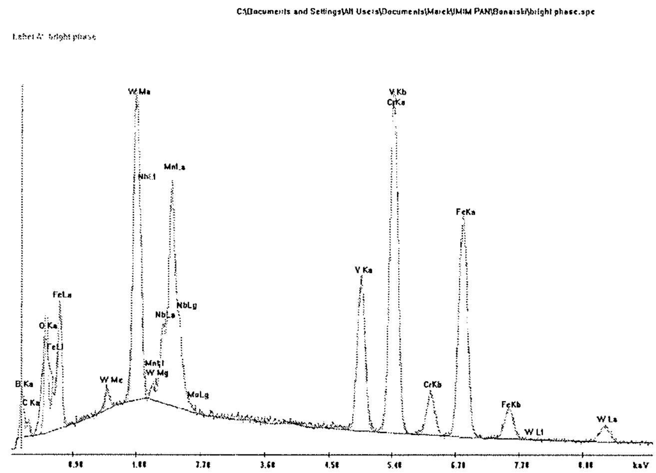

Fig. 5. The microanalysis of minute white precipitates in the structure of the padded layer in the "white" phase

The realized analysis allowed us to identify the phase arrangement of the microstructure of the padded layer and to identify three characteristic phases [10]:

- the "grey" phase (the matrix): large amounts of Fe (84%) and the presence of Cr (6.8%), W (1.2%), and C (6%), V (0.9%) and Mo (0.6%). Precipitates with sharp edges (Fig. 1) are clearly visible. The presence of particular elements in this phase are presented in Fig. 2.
- The "dark grey" phase contains Fe, Cr, V, Mo, C (Fig. 3). The phase has a strip structure with the microstructure difficult to identify (Fig. 1).
- The "white" phase contains W, Mo, Nb (Fig. 4). It contains sharp-edged precipitates in the form of squares and triangles, characteristic for borides and carbides (Fig. 1).

Moreover, the entire analyzed area contained numerous crystals of niobium boride, which appear as minute white precipitates in the microstructure, as well as empty space appearing as small black and irregular points (Fig. 1 and 5).

Ballistic examination

The examination of the efficiency of the system consisting of a padded layer and a steel sheet metal (substrate) were carried out in a shooting tunnel. The sample was subjected to single shots, realized with the ammunition described in point 2. The shooting was realized from the distance of 10 m. Bullets hit the padded surface at the right angle. The speeds and energies of impact of the bullets are presented in Table No. 1, while the places of bullet impact in a sample are illustrated in Fig. 6.

TABLE

Results of ballistic tests

No.	Ammunition type [caliber]	Impact speed [m/s]	Impact energy [kJ]	Final test result
1	7.62×39 AP BZ	721	2.08	no penetration
2	7.62×51 AP	822	3.31	no penetration

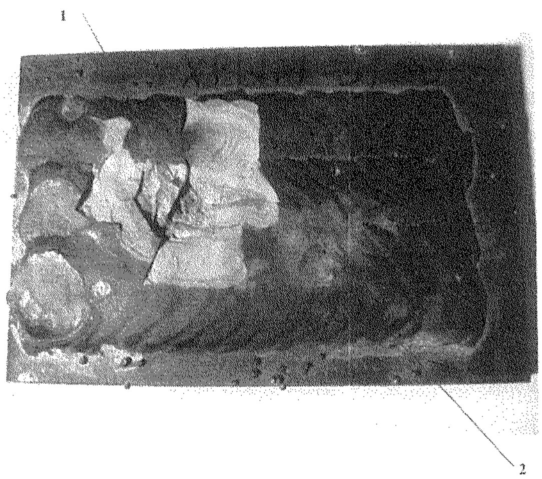

Fig. 6. The examined sample made of steel sheet metal with a padded composite layer. The impact places are indicated as: 1 – 7.62×51 AP; 2 – 7.62×39 AP BZ. Visible fire consequences in the padded layer

The analysis of the bullet impact places indicates, that the padded layer is slightly crumbled, when the impact energy reaches the value of about 2.1 kJ. The bullet core did not penetrate into the sample, which means, that it crumbled on the padded layer. In the case the bullet impact energy reached 3.3 kJ, the degree of destruction of the padded layer is much higher. There appeared cracks in the layer and the layer was destroyed. The destruction takes the form of a surface shell-shaped splitting, which moves into the layer. The layer was not totally destroyed, neither did it loose cohesion to the substrate. The bullet core was partly defragmented, and the fragments got stuck in the transitory zone, i.e. between the substrate and the padded layer, which resulted in a deformation of the soft steel substrate of the sample.

To sum up: a crumbled fragment of the core penetrated into the sample at this level of bullet energy, but the bullet energy was not sufficiently high to penetrate the padded weld substrate and it was used to produce a plastic deformation of the substrate.

4. Conclusions

- A composite layer made of padded metal powders on a substrate soft steel sheet metal is characterized by high hardness (73 HRC) and cohesion, sufficient to defragment a hard armour-piercing bullet core (about 65 HRC).
- The examination of microstructure allows one to say, that the high hardness of the composite layer results from the fact, that there appear carbides and borides in the iron phase during the process of padding, which ensures the layer is coherent.
- Examinations confirmed the hypothesis, that the arrangement of layers is characterized by a hardness gradient (hard padded layer – soft substrate), which efficiently protects it against the impact of bullets with high impact energy.
- The protective efficiency of a steel armour can be increased by padding with metal powders with an appropriate chemical composition.

Acknowledgements

The author wish to thank Dr. M. Faryna from IMMS of the PAS in Kraków for his help in microstructure observation. The work was financially supported by the Ministry of Science and Higher Education within the Research Project No. N508-O/0025/32.

REFERENCES

[1] E. Włodarczyk, Balistyka Końcowa Pocisków Amunicji Strzeleckiej. WAT Warszawa 2006.

[2] R. M. Jones, Mechanics of Composite Materials Mc Graw-Hill Book Company. New York 1975.

[3] S. W. Tsai, H. T. Hahn, Introduction to Composite Materials. Technomic Publishing Co. Inc. Stamford Connecticut 1980.

[4] B. A. Gama, J. W. Gillespie, T. A. Bogetti, B. K. Fink, Innovative Design and Ballistic Performance of Lighweight Composite Integral Armor. Technology for the Army's Transformation. SAE World Congress and Exposition. Detroit March 5-8, 2001 Paper No.2001-01-0888.

[5] L. Starczewski, Wnioski z realizacji projektu badawczego stali przeznaczonych na pierścienie wiodące pocisków artyleryjskich. Materiały III Konferencji Naukowo-Technicznej "Amunicja 2002" Kołobrzeg 2002.

[6] L. Starczewski, Badanie i modelowanie złożonych procesów zużycia. Materiały Seminarium Naukowo-Technicznego Szczecin 2003.

[7] L. Starczewski, J. T. Bonarski, Monitorowanie zmian struktury obszarów przypowierzchniowych spowodowanych procesem tarcia. Tribologia nr 3/2001.

[8] J. Bonarski, X-ray texture tomography of near-surface areas, Progress In Materiale Science, **51**, 1, 61-149, January 2006.

[9] D. R. A s k e l a n d, The Science And Engineering of Materials PWS-Kent Publishing Company Boston Massachusetts 1984.

[10] M. F a r y n a, Analiza zależności krystalograficznych faz składowych w kompozytach z osnową ceramiczną. Wyd. IMIM PAN Kraków 2003.

Received: 3 December 2007.