HIGH-STRENGTH SYNTHETIC FIBERS AND NANO-SIZED PARTICLES OF SiO_2 COMBINED INTO ONE COMPOSITE SYSTEM FOR BALLISTIC PROTECTION

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ABSTRACT. Aramid, polyvinyl alcohol, and nanoparticles of SiO_2, combined in a single composite system for individual ballistic protection is presented. Physico-mechanical and ballistic tests confirm that balistic resistance increases with increasing the content of polyvinyl alcohol together with nanoparticles of silicon oxide in the system thus created. Scanning electron microscopy shows a relatively uniform distribution of SiO_2 particles on the surface of the aramid before and after the ballistic studies.

Keywords: ballistic protection, aramid, SiO_2, polyvinyl alcohol

ВИСОКОЯКОСТНИ СИНТЕТИЧНИ ВЛАКНА И НАНОРАЗМЕРНИ ЧАСТИЦИ НА SiO_2 ОБЕДИНЕНИ В ЕДИННА КОМПОЗИТНА СИСТЕМА ЗА БАЛИСТИЧНА ЗАЩИТА

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РЕЗЮМЕ. Представена е композитна система на основата на арамид, поливинилов алкохол и наноразмерен SiO_2, предназначена за индивидуална балистична защита. Физико-механичните и балистичните тестове потвърждават, че балистичната устойчивост нараства с нарастващото съдържание на поливинилов алкохол и количества наноразмерен силициев диоксид. Сканиращата електронна микроскопия показва относително равномерно разпределение на частици SiO_2 върху повърхността на арамида, преди и след балистичните изследвания.

Ключови думи: балистична защита, арамид, SiO_2, поливинилов алкохол

Introduction

The term "nanotechnology" was first used in 1959 when the famous American physicist Richard Feynman gave a lecture on the topic "There is plenty of space on the bottom" which later became classical and has often been quoted. It proves that the principles of physics do not contradict the attempts to drive atoms by atom, as long as the necessary instruments are available.

Many experts compare the creation of nanotechnology to a second industrial revolution. From a scientific point of view, it is a way of influencing the matter below the molecular level.

Nanotechnology allows the exploration and use of very small structures and systems. The result of the use of nanotechnology is new materials, devices, and products with qualitatively different characteristics. In practice, they have the potential to be applied in every economic area and aspect of public life, including in warfare and in particular for the development of tissues for military purposes.

In recent years, the assortment of textiles has been significantly expanded by the application of chemical fibres and the blending of different fibre properties, which produce textile materials with improved hygienic properties or improved physical, mechanical, and ballistic indicators.

The complex of properties, which have the fibres together with nano powder, determine their practical significance. Through the methods and means of the special finishing, it is possible to yield new fibres that are necessary due to the different areas of their use.

The construction of the ballistic protection products requires the use of materials to create lightweight but sturdy armour. In order to be able to create such a product, it is necessary to select materials that possess strength, weather resistance, and last but not least, are of low weight. The combination of properties of metal alloys, synthetic fibres, polymeric materials, nanoparticles through their reinforcement in a single composite matrix can provide high ballistic protection.

Like other nanomaterials, the agglomeration of SiO_2 nanoparticles has seen the obstacles against their wide applications (Zhang et al., 2004, Li et al., 2004). The characteristics of nanoparticles are hardly embodied in usage because they are usually dispersed in medium in aggregation of micro-size (Ke, 2002). So, the study of improving dispersivity of nano-silica in organic solvents has raised considerable interest recently. Generally, fumed silica made by a costly method has good dispersivity while precipitated silica particles are difficult to be dispersed into organic solvents (Wang at all, 2002). Many investigators treat precipitated nano-silica particles with coupling agents, surfactants, aliphatic acids, etc., but hardly make them well dispersive in organic solvent. This is because the unsaturated dangling bonds and hydroxyl groups are extremely active and they are saturated as soon as the SiO_2 is exposed to air. So the modifiers are difficult to react with the active groups of SiO_2. Moreover, partial agglomeration usually occurs before the modification.

Polyvinyl alcohol (PVA) is a versatile and industrially significant polymer, possesses good strength, and creates resistant roof layers. This polymer is used as a substance and creates good soldering for ceramic and metal powders. PVA, when based on nano-composites, is usually used for the production of thin films that are used in Industry. The addition of nanoparticles to polyvinyl alcohol improves its mechanical properties. The added nanoparticles, to which the surfaces have been modified, are used to provide strength by providing surface soldering between the polymer and the nanoparticles, which significantly improves the mechanical properties of the compounds. Homogeneous distribution of particles can be achieved by their organic modification which creates superficial interactions between the particles and the polymer. Broadly speaking, the reinforcement by nanoparticles in laminate compounds develops the bonding of fibers into a matrix and reinforces the properties of the matrix. With their minimum weight and small size, rigid nanofillers are used to improve the plasticity and hardness of the compounds (Obradovi et al., 2017).

The present study aims at presenting a composite system suitable for lightweight protective armour to be incorporated into a ballistic protection product. Combining the properties of heterogeneous materials in a single composite matrix can provide both reliable protection and necessary mobility during combat operations.

For the creation of sturdy armour, it is necessary to combine the properties of three types of different materials to create high strength armour: used woven synthetic fibres from the group of Aramid, nano-sized particles based on silicon oxide, and highly viscous fluid based on polyvinyl alcohol.

Experimental procedure

Preparation of the composite system

The type of aramid used was Style 363, with a mass of 180 g/m^2, thread strength of 200 cN/tex, and density between the fibres 120/120 threads/cm. Each of the layers was treated by the impregnation method by dipping, as shown in Figure 1. Each part of the samples contained ten canvases of aramid, each measuring 20 cm^2. PVA-based impregnating liquid was prepared, with a different concentration of glacial acetic acid and nano-sized particles of silicon oxide. Drying of the samples was at room temperature.

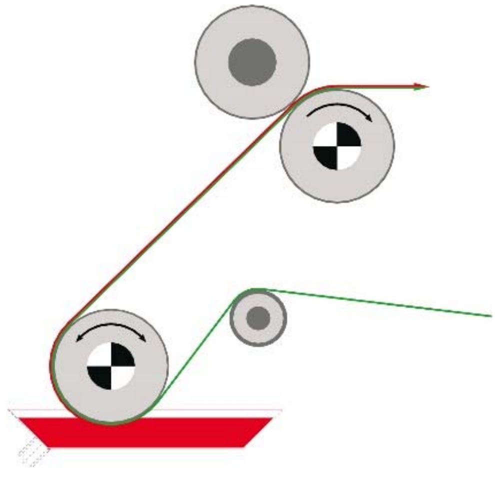

Fig. 1. Textile fabric impregnation plant, dipping method

Different concentrations and compositions of impregnating solutions are designed to track the impact of substances and nanoparticles on the strength, weight, and ballistics of composite systems. Samples of unprocessed Kevlar, aramid treated with polyvinyl alcohol (20 pph PVA), and aramid sheets treated with polyvinyl alcohol (PVA) solutions with different content of CH_3COOH and micro- and nanoparticles of SiO_2 particles were prepared where:
D_{part} = 18nm
and
S_{cn} = 210m^2/g.

Physico-mechanical test

Physical and mechanical tensile strength tests were conducted on a WPM *Shoper* dynamometer, and complied with the requirements of (BDS EN ISO 13934-1, 2013). The prepared samples were 10 mm wide and 100 mm long. The mass measurement was carried out according to standard (BDS EN 12127, 2016).

Ballistic tests

Ballistic tests were conducted in accordance with the Ballistic, (STANAG 2920 Ed.3.). The ballistic test set is shown in Figure 2.

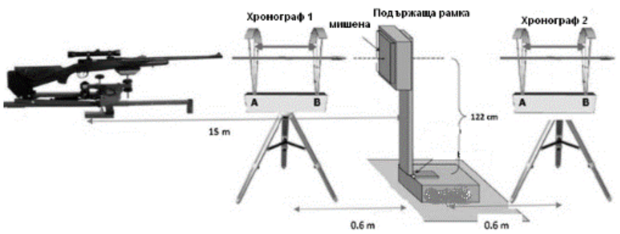

Fig. 2. Diagram of the installation for conducting ballistic tests

The boundary ballistic velocity V50 with an imitator of fragments under conditions of environmental 20 ^{0}C and a relative humidity of 82,0 ± 1,5 were defined. The shooting was conducted with a caliber of the barrel 7.62x39 mm, impersonator fragments A3/7623 mass 1.102 ± 0.02 g, direction of the barrel 00±10, and distance between the barrel end and the panel 5 m ± 50 mm. The number of projected shots was ten punctured and ten not punched. The distance between the hits was > 30 m on the sample. Packets of 10 layers were prepared for all proportions.

Analysis of results

An analysis of the results of the tests carried out is shown in Table 1 and Fig 3, 4, and 5.

Table 1.
Data from physico-mechanical, weight, and ballistic tests and samples of different composites reinforcement materials

№	Composite system	Tensile strength [N]	Mass [g/m²]	Average ballistic speed V_{50}, [m/s]
0	Aramid	1933	187,5	342; Δ=14
1	PVA/Aramid/	2216	250	355; Δ=23
2	PVA/aramid/10pph CH_3COOH/	2206	199	360; Δ=20
3	PVA/aramid/20pph CH_3COOH/	1617	196	344.8; Δ=29
4	PVA/aramid/30pph CH_3COOH/	1463	205	350; Δ=28
5	PVA/aramid/10pph CH_3COOH/0,5 g **SiO_2**	1961	238	393; Δ=36
6	PVA/aramid/20pph CH_3COOH/0.5 g **SiO_2**	2075	232	368.3; Δ=38
7	PVA/aramid/30pph CH_3COOH/0.5 g **SiO_2**	2143	196	369; Δ=32
8	PVA/aramid/10pph CH_3COOH/1.4g**SiO_2**	2229	242	399; Δ=34
9	PVA/aramid/20pph CH_3COOH/1.4g **SiO_2**	2143	236	389.3; Δ=35
10	PVA/aramid/30pph CH_3COOH/1.4g **SiO_2**	2387	215	409; Δ=31

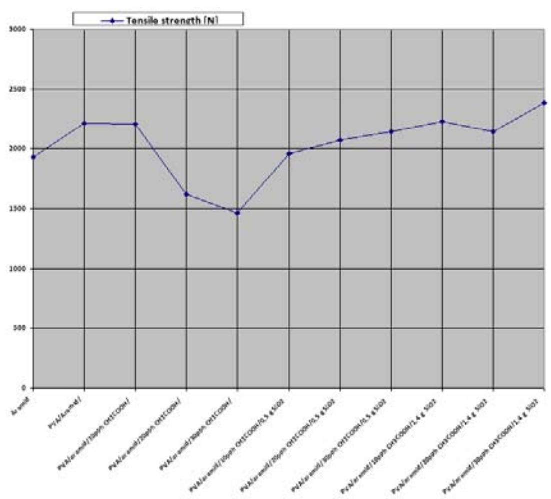

Fig 3. Results of the tensile strength tests

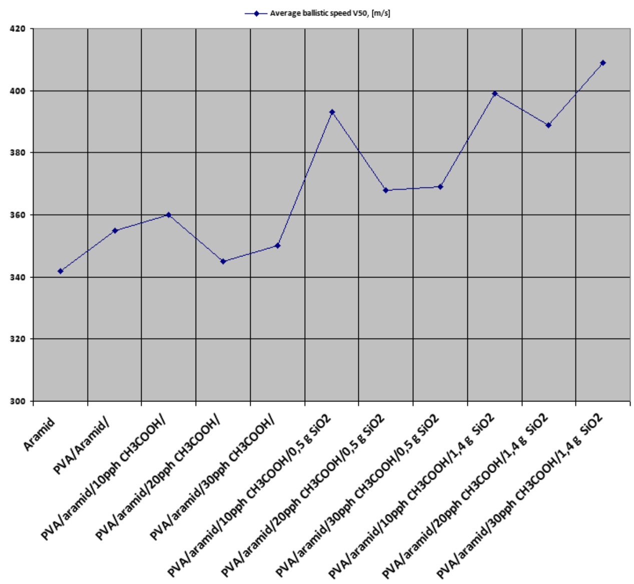

Fig 4. Results of the weight tests carried out

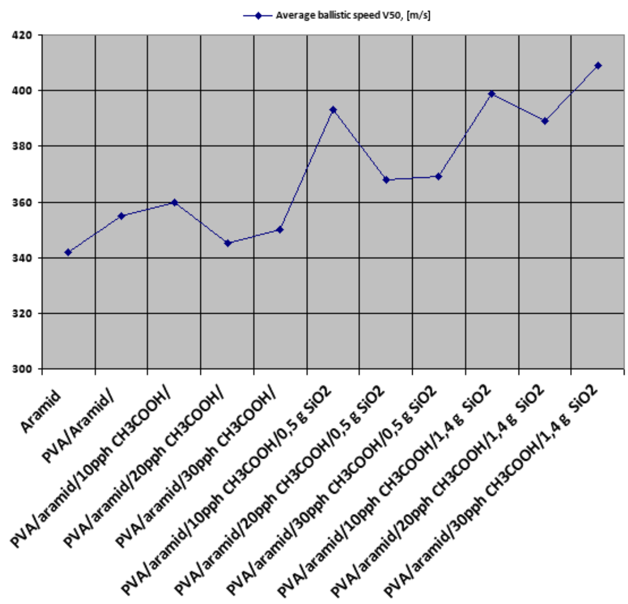

Fig 5. Ballistic test results

The results of the conducted tests show an improvement of tensile strength of the samples treated with PVA compared to the untreated samples (pure aramid). The addition of higher concentrations of 10 pph CH_3COOH to the PVA/aramid system worsened the results for two of the parameters - tensile strength and mass. The addition of nano powder SiO_2 to the PVA/Aramid system has led to an increase in the average ballistic speed of V50 in comparison to the untreated aramid, with a slight increase in weight. It should be noted that the average ballistic speed V 50 significantly increases in the PVA/aramid/10pph CH_3COOH/0.5g SiO_2 and PVA/aramid/10pph CH_3COOH/1.4g SiO_2 samples. The comparison of the results of three parameters, which were researched, shows that the PVA/aramid/30pph CH_3COOH/1.4g SiO_2 sample has the best values for tensile strength and average ballistic speed, and low for mass.

Results of scanning electron microscopy

The morphology and elemental composition of nano emulsion treated samples were screened using scanning electron microscopy and energy dispersion elemental analysis (JEOL JSM 6390 scanning electron microscope and INCA Oxford solid-state X-ray detector). Micrographs taken in secondary electrons (particle morphology and fibre thickness) were used. Figures 6 to 11 show an image in backscattered electrons. This is a semi-quantitative analysis in which the deposited particles are seen as lighter objects. A high carbon content is observed, and some oxygen, nitrogen, and significant amounts of silicon. The elements thus detected prove deposited nano particles on the surface of the aramid fibers.

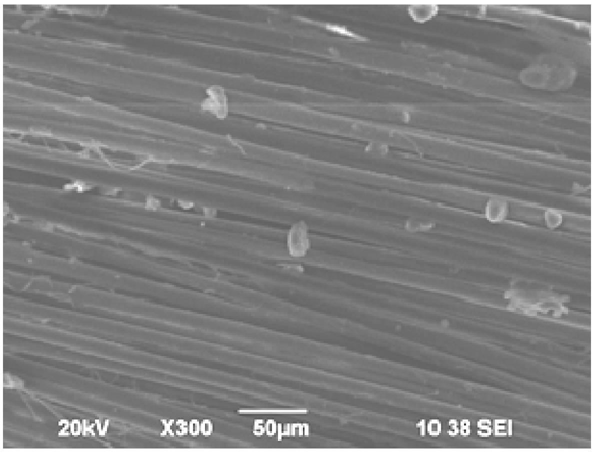

Fig 6. Scanning electron microscopy of x300, 50μm, 10 38 SEI, shows a particle with a complex embossment on the basis of Si

Table 2.
Detected elements of spectral analysis of composite: PVA/aramid/10pph CH_3COOH/0,5 g SiO_2.

Spectrum, atomic % ,till 100 %	C	O	Si
Spectrum 15	48.47	41.82	9.39
Spectrum 16	30.14	47.26	2.15

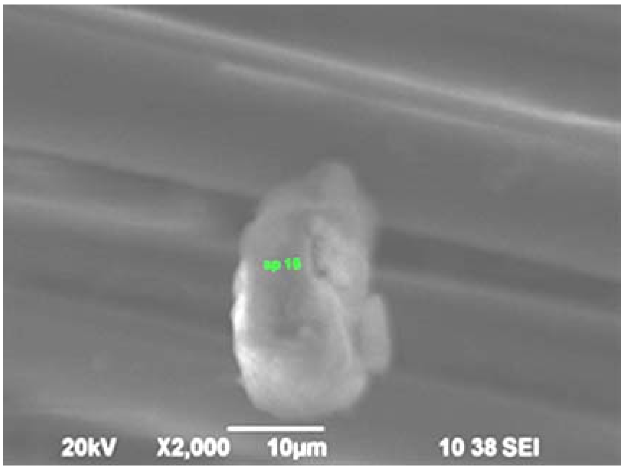

Fig 7. Scanning electron microscopy of deposited nanoparticulate SiO_2 on aramid fibers "Style 363" treated with polyvinyl alcohol at an magnification of 2000, 10μm, 10 38 SEI.i

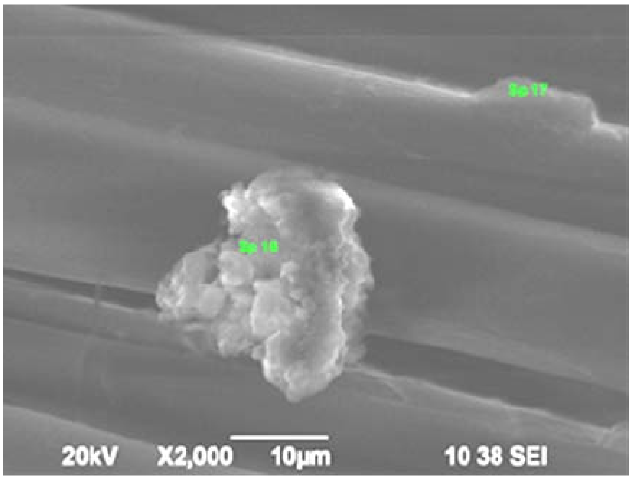

Fig 8. Scanning electron microscopy of deposited nanoparticulate SiO_2 on aramid fibers *Style 363* treated with polyvinyl alcohol at a magnification of 2000, 10μm, 10 38 SEI shows a particle with a complex embossment on the basis of Si

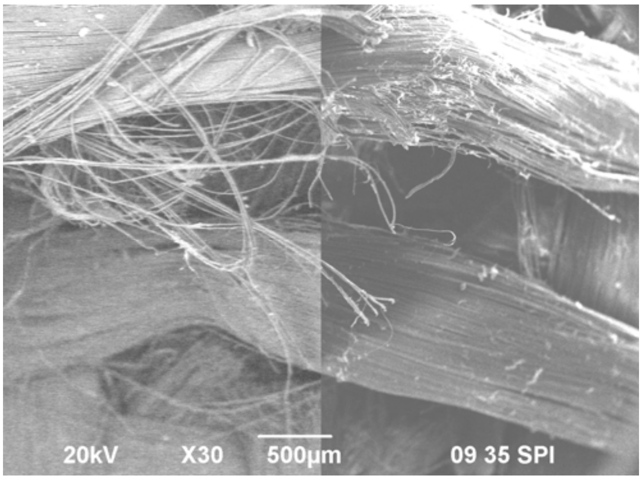

Fig 9. Scanning electron microscopy after ballistic test at a magnification of 30, 500μm, 09 35 SEI

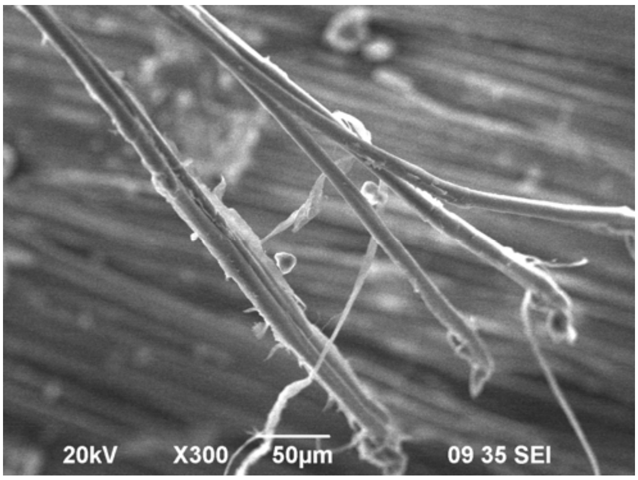

Fig 10. Scanning electron microscopy after ballistic test at a magnification of 300, 50μm, 09 35 SEI

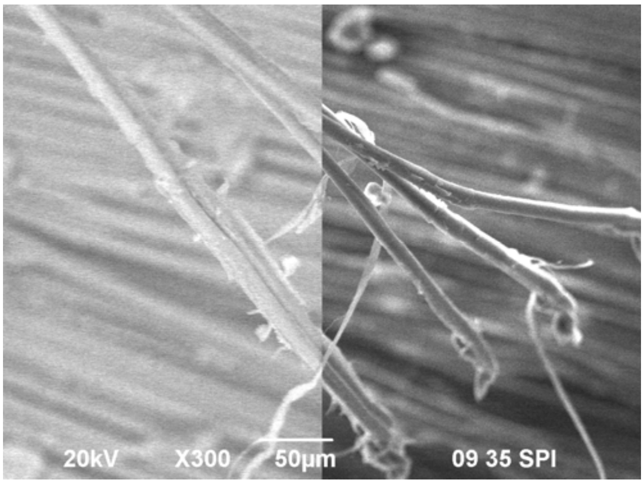

Fig 11. Scanning electron microscopy after ballistic test at a magnification of 300, 50μm, 09 35 SEI

Conclusions

As a result of the conducted experiments and the results obtained, the following conclusions can be drawn:

1. The added acetic acid to the PVA solution helps maintain the strength of the fabric and at the same time reduces the mass of the sample, which would help to completely lighten the ballistic equipment.
2. The addition of nano-sized particles of silicon oxide increases the limit ballistic velocity of the test samples.
3. The results of the scanning electron microscopy confirm the presence of deposited nano-sized silicon-based particles. Microscopic images confirm that after the ballistic tests, the reinforcement matrix of PVA, together with nanomaterial silicon oxide, remains on the surface.

The tests carried out confirm that the composite system thus created is suitable for designing ballistic protective armour not only for people but also for the paint field technique.

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