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EDITORIAL OFFICE:
International Journal “NDT Days”
Institute of Mechanics, Bulgarian Academy of Sciences
Acad. G. Bonchev Str., Block 4, Sofia – 1113, Bulgaria
phone: +359 2 9797120
e-mail: ndtdays@abv.bg
http://www.bg-s-ndt.org/journal.html
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NDT събития у нас и по света
Interaction of Radiowaves with a Polymer Composite Electromagnetic Screen

Vadim KOVTUN1, Victor BANNYI2, Mitko MIHOVSKI3, Yordan MIRCHEV3

1 Gomel Branch University of Civil Protection of the Ministry for Emergency Situations of the Republic of Belarus; Gomel, Belarus; e-mail: vadimkov@ya.ru
2 Gomel State Medical University, Gomel, Belarus
3 Institute of Mechanics at the Bulgarian Academy of Sciences, Block 4, Acad. G. Bonchev Str., 1113 Sofia, Bulgaria
Phone: +359 2 9797120; e-mail: nntdd@abv.bg, mirchev@imbm.bas.bg

Abstract
The present work is devoted to elaboration of representations on the mechanism of super high frequency radiation interaction with heterogeneous systems based on condensed media. The aim was to develop a systematized approach to creation of polymer composite electromagnetic screens. In this connection, a physical model of the polymer composite electromagnetic screens has been developed and its mechanism has been analyzed. Polymer composite absorbers of super high frequency radiation are proposed with reflectance and energy attenuation of electromagnetic waves optimized via choosing the required composition, dimensions and structural parameters.

Keywords: electromagnetic screens, radioabsorbing materials, electromagnetic radiation, radiowaves, physical models, polymer composite, thermoplastic binder, physico-chemical interactions.

1. Introduction

To the best of our knowledge, there is not as yet [1] any reliable theoretical approach able to forecast electromagnetic parameters of composite radioabsorbing materials (RAM), particularly ferroplastics, within a wide range of concentration of components and frequency of the outer electromagnetic field. In spite of availability of a series of theoretical methods for computing electromagnetic waves (EMW) absorbers [2–4] ready to define the desired limits of the magnetic, dielectric and Joule losses, there still exists a paradox in this physical domain of using the cut and try method in creating RAM and electromagnetic screens (EMS). Nevertheless, there have been elaborated the basic elements of a systematized approach to the development of the broadband EMS on the base of filled thermoplastics. Research workers in the physics of condensed state have established the mechanism by which the microwave radiation interacts with the matter. Moreover, the interaction schemes of electromagnetic radiation (EMR) with the screens and physical models of EMS based on certain condensed substances are proposed.

The aim of the work was to develop the notions on interaction of super high frequency radiowaves with the polymer heterogeneous systems. It is evident that the development of the physical model of thermoplastic-based EMS along with optimizing the composition and structure of the polymer solid and fibrous RAM by the criteria of reflectance and energy attenuation of radiowaves can solve a number of problems in protection of electronic facilities from harmful radiation and provision of electromagnetic ecological safety.

2. Physical models of polymer composite EMS

Some single-layer, structurally isotropic EMS fail to ensure sufficiently low EMW reflectance factor within a given frequency range [1, 2]. This is mainly because of a poor matching of the impedances of these EMS and the free space. The single- and multilayered EMS of the gradient
type are devoid of this drawback owing to either smooth (Fig. 1a) or stepwise (Fig. 1b) increase of the electric and magnetic losses in direction of EMW propagation when the dielectric and magnetic permittivity values of the air and absorber are brought to a minimum at the interfaces [2, 5]. In the first case (Fig. 1a), the gradient of losses is conditioned by the filler content increment across thickness of the composite EMS. The original processes are employed to produce mentioned EMS, particularly, the ones with sedimentation effects in the polymer melt. The gradient of electromagnetic properties in the laminated inhomogeneous systems is dependent on the number of RAM layers, their thickness and functional filler (FF) content in each layer.

Fig. 1. Cross-sections of single-layer (a) and multilayer (b) EMS with gradient of electric and magnetic losses in direction Z of EMW propagation:

\[ \varepsilon_0 \approx \varepsilon_k < \varepsilon_{k-1} < \ldots < \varepsilon < \varepsilon_1; \mu_0 \approx \mu_k < \mu_{k-1} < \ldots < \mu < \mu_1; \]

1 – reflecting substrate;

2 – polymer material with dispersed filler ensuring electric and magnetic losses

Figure 2 presents a diagram illustrating the performance of the gradient EMS based on a polymer binder and FF particles with increasing across thickness concentration in direction of EMW propagation. Let us take the following assumptions: the polymer binder is radioparent; FF particles of one origin are spherical; EMW propagates normal to the screen surface.

Fig. 2. Scheme of a model of polymer gradient EMS
Energy losses of EMR in the gradient screen are equal to the difference of the incident $E_0$ and having passed radiation energy $E_h$ through the EMS, which present a sum of EMR energy constituents contributing to absorption $E_A$, scattering $E_S$ and reflection $E_R$.

$$\Delta E = E_0 - E_h = E_A + E_S + E_R. \quad (1)$$

With account of the gradient distribution of FF particles in the sample,

$$\Delta E = \sum_{i=1}^{N} E_{Ai} + \int_{0}^{h} (E_S(x) + E_R(x)) \frac{dn}{dx} dx + E_\xi, \quad (2)$$

where $N$ – total number of FF particles in the sample; $h$ – sample thickness; $dn$ – number of FF particles within the layer of $dx$ thickness; $E_{Ai}$ – EMR energy value absorbed by one particle; $E_S, E_R$ – values of EMR energy scattering and reflection at a distance $x$ from the screen surface; $E_\xi$ – energy attenuation by the screen owing to radiation absorption at the boundaries of thermoplastic binder and FF particles.

The value of $E_\xi$ is conditioned by physico-chemical interactions of the polymer binder with FF material, which alter essentially the composite structure and properties [6]. This constituent should be accounted for when forecasting the efficiency of the polymer composite EMS.

The experimental investigations [7, 8] have made grounds for determining an optimum filling degree (40-60 mass %) of the outer PE-based layer of the screen by ferromagnetic particles, for which value the reflectance factor of the screen is the minimal. If met, this condition eliminates the necessity of the external radioparent coatings on the radioabsorbing elements aimed at the impedance matching of the element and atmosphere.

Figure 3 shows a physical model of a laminated EMS whose layers realize consecutively the chief mechanisms of the EMR energy transformation.

![Fig. 3. EMS model consisting of matching dielectric (D), magnetic (M) and conducting (C) layers](image)

The screen is modeled by three layers: the external dielectric (D) that allows for matching impedances of the screen and atmosphere, the magnetic layer (M) and the conducting one (C). Energy losses of the EMR penetrated through the screen present a sum of the losses in the layers, namely dielectric $E_D$, magnetic $E_M$ and the ones generated by electric conductivity $E_C$, plus the energy attenuation at the interfaces $E_{DM}$ and $E_{MC}$.
\[ \Delta E = E_0 - E_h = E_D + E_M + E_C + E_{DM} + E_{MC}. \] (3)

If to take into account physical parameters of the layers (\(\varepsilon\) and \(\mu\) - dielectric and magnetic permittivity, \(\gamma\) - specific conductance), their thicknesses \((h)\) and interfacial behavior in the contact zones, relation (3) can be presented as a sum of the functions:

\[ \Delta E = F_D(\varepsilon_D, h_D) + F_M(\mu_M, h_M) + F_C(\gamma_C, h_C) + F_{DM}(\varepsilon_{DM}, \mu_{DM}) + F_{MC}(\mu_{MC}, \gamma_{MC}). \] (4)

3. Optimizing of composition and technique of polymer RAM and EMS.

The models of EMS set forth above have stipulated a series of experimental investigations fulfilled by the authors for optimizing the composition and the process of RAM formation. Herein below the investigation results are cited for the RAM based on a polymer binder and containing conducting and magnetic fillers in different amounts and dispersion degree. RAM samples were obtained by hot pressing from the mixtures of powder polyethylene (PE) (URSS GOST 16803-070) and fillers, including carbonyl iron (CI) (URSS Techn. Spec. 6-09-300-78), magneto-soft ferrite (MSF) (URSS Techn. Spec. 6-09-5111-84, grade 2500 HMC) and nickel (URSS GOST 9722-78). The reflectance factor \((R)\) and energy attenuation \((S)\) of the microwave radiation were recorded by the method of scatterometry in the 2-27 GHz frequency range at normal incidence of EMW on the object under study in the waveguide tracts (R2-50; R2-60, R2-61, R2-65, R2-66) for the standing wave ratio and attenuation. The dependencies of \(R\) for the normal incident plane EMW \((\nu = 8-12 \text{ GHz})\) versus sample thickness, filler concentration and dispersivity have been determined. The dependence of \(R=f(h)\) (Fig. 4) for RAM samples with 50 mass % filling degree is in the form of degenerating sinusoids with a \(\lambda/4\) period. The minimal \(R\) values correspond to thicknesses \((h)\) till a 15 % accuracy of the samples described by next equation [7, 9]:

\[ h = \frac{\lambda}{K} + z\frac{\lambda}{4}, \] (5)

where \(K\) – the factor interrelated with magnetic permittivity values of ferromagnetic fillers, while \(z\) – equals to zero or a positive integer.

Fig. 4. Reflectance factor \((R)\) of 12 GHz frequency EMW depending on sample thickness \((h)\) and kind of FF: 1 – carbonyl iron, 2 – magneto-soft ferrite, 3 – nickel.
The concentration of the ferromagnetic components in the subsurface layer of the sample at the interface with the atmosphere affects $R$ magnitude. Concentration ($C$) of ferromagnetic components in the surface layer of the sample at the interface with the atmosphere effects $R$ value. For all studied fillers the dependencies $R=f(C)$ show a minimum at 40-60 mass % at a similar sample thickness and fixed EMR frequency in the 8-12 GHz range. This is related to a competing effect of some processes. Firstly, introduction of the ferromagnetic filler in the radioparent PE binder results in a growth of magnetic losses in the material and reduction of $R$. Secondly, as the filling degree increases $C > 60 \%$ mismatching of impedances of the sample and atmosphere increments leading to $R$ growth.

Radiophysical characteristics of the composite samples were found to depend upon the dispersion of FF as well as physico-chemical interactions of the filler particles with the polymer binder. PE-based 3 mm thick samples filled by MSF (50 mass %) differed in the filler dispersivity. The dependence of $R$ on the filler dispersivity (Fig. 5) confirms that the optimal filler particle size providing for a strongest radioabsorption, all other conditions being equal, depends on the EMR frequency [9, 10]. This is because: 1) the ferrites of different dispersivity acquire different parameters of electromagnetic losses in the EMR field; 2) the conditions of EMW scattering change depending on the ratio of the filler particle size to the incident wavelength. Proceeding from the above, it follows that to create a wideband screen one should employ the polydispersed FF particles.

It has been shown on the example of PE filled by MSF of two fractions (50-63 μm and 160-200 μm) that the reflectance factor of EMW can be regulated within 30 % limits by altering the ratio of coarse and fine filler particle content ($l/s$) in the polymer matrix of RAM (Fig. 6). Keeping all other conditions equal, the minimal reflection shifts along the $l/s$ scale as a function of EMR frequency and the ratio of dispersion values of the coarse and fine particles. The non-monotonous behavior of EMR attenuation curve depending on $l/s$ can be explained by the varying relation of the EMW scattering intensity versus that of the EMR energy absorption by the samples.

The effect of the new phases arising at thermal forming of filled polymer composites has been studied by varying time and temperature regimes, all other conditions being equal. A correlation between the forming temperature and radiophysical parameters of the samples has been
established for the PE−CI composite. This is because named parameters \((R, S)\) are dependent on the oxidation degree of iron particles being, in its turn, a function of RAM formation temperature (Fig. 7).

The minimal value \(R \approx 7\%\) and EMR attenuation down to \(S = 5-6\) dB are observed at \(T = 210^\circ\)C corresponding to a maximal adhesion of PE to iron [11] in 3 mm thick samples and 10 GHz EMR frequency. This is evidently, caused by the dependence of the stoichiometric composition of iron oxides \((\text{FeO, Fe}_2\text{O}_3, \text{Fe}_3\text{O}_4)\) on the heating temperature of the composition during sample formation and by different structure of the newly formed metal-polymer phases appearing at PE−CI boundaries. Consequently, different oxides and metal-polymer phases are characterized by different radiophysical parameters. The experimental results show the necessity of considering the interaction at the binder-FF interface presented within the models of the gradient and laminated composite EMS (formulas 2 and 4).

Hence, there must be some optimal thickness, filling degree, dimensions and coarse to fine FF particle ratio for the composite PE-based RAM in whose polymer matrix different-nature FF particles are distributed in the isotropic manner so as to attenuate EMW energy to the utmost. When optimizing dimensional, composition and structural parameters of the screens aiming at EMR energy attenuation, it is important to ensure not only high dielectric and magnetic losses...
but also impedance matching of the RAM with the free space and intensified scattering effect of EMW at the interfaces in the bulk.

Proceeding from above-mentioned principles of optimizing EMS by the criterion of EMR energy attenuation, the authors have elaborated sheet radioabsorbers based on PE and dispersed FF. Frequency dependencies of $R$ and $S$ recorded in the waveguide for the radioabsorbing laminated plastics reinforced by conducting fabrics and these of the polymer composite RAM filled by metallized fibers and/or glass spheres are illustrated in Figs. 8 a and b, correspondingly.

Fig. 7. Adhesion ($A$) of PE to steel, reflectance factor ($R$) and attenuation of EMR energy ($S$) versus forming temperature for RAM samples.
Composition of samples: PE + CI (50 mass %), $h = 3$ mm
Fig. 8. Frequency dependencies for \( a \) – reflectance factor \( (R) \) and \( b \) – attenuation \( (S) \) of the energy of normal incident plane EMW (in waveguide) for 3 mm thick RAM samples.

Sample composition: 
1 – PE + MSF (50 mass %, \( d = 50\ldots200 \, \mu m \));
2 – PE + MSF (50 mass %, \( d = 50\ldots200 \, \mu m \)) + glass spheres (10 mass %, \( d = 200\ldots500 \, \mu m \));
3 – PE + MSF (50 mass %, \( d = 50\ldots200 \, \mu m \)) + carbon fabric TR3/2

The filling of the polymer binder by glass spheres as well as reinforcement of the composite RAM by the carbon fabric is seen to improve both \( R \) and \( S \). This is attributed to the effect of several factors. Firstly, the increasing total amount of FF results, as a rule, in growing magnetic, Joule’s and dielectric losses of the falling on the RAM microwave radiation (at optimized filling degree by the criterion of the minimal EMW reflection). Secondly, parameters \( R \) and \( S \) improve under an optimal correlation of different mechanisms of the losses and, thirdly, they do improve owing to the optimized conditions of EMR scattering over the structural inhomogeneities of the composite.

4. Conclusions

Proceeding from the analysis of attenuation of the microwave energy by the filled thermoplastics an interaction scheme of EMR with the polymer composite EMS is proposed. A physical model for the EMS has been developed and the criteria for selecting its ingredients have been substantiated. The developed scheme and model evidence that in fact all mechanisms of radiation reflection, absorption and scattering can be realized by the polymer composite screens. A relation is proposed to describe the losses of the EMR energy passing through the screen, which takes into account the concentration gradient of FF in the polymer binder and formation of new phases due to physico-chemical interactions between the polymer and FF during thermal processes of EMS forming. This broadens functional resources of the thermoplastic-based RAM filled by different in nature, size and structure FF. The EMS from described materials are characterized by high manufacturability, small density and elevated specific strength.
5. References


Deformation Induced Martensite Formation in TRIP (Transformation Induced Plasticity) Steels

Stoyan PARSHOROV\textsuperscript{1}, Petar PETROV\textsuperscript{2}, Rumiana LAZAROVA\textsuperscript{1}, Rosiza DIMITROVA\textsuperscript{1}, Stefan VALKOV\textsuperscript{2}

\textsuperscript{1} Institute of Metal Science, Equipment, and Technologies with Hydro- and Aerodynamics Centre “Acad. A. Balevski” at the Bulgarian Academy of Sciences, Sofia, Bulgaria, Phone: +359 24626 361; e-mail: s.parshorov@ims.bas.bg, lazarovarumiana@abv.bg, rossy@ims.bas.bg.
\textsuperscript{2} Institute of Electronics-BAS, Sofia, Bulgaria, pitiv@ie.bas.bg, stsvalkov@gmail.com

Abstract
The influence of the quantity and the type of the alloying element in TRIP-steels on the tendency for deformation induced martensite formation during plastic deformation is investigated.

Keywords: austenitic metastable steels, deformation induced martensite, alloying element, TRIP-steels

1. Introduction
The aim of the present work is to investigate the influence of the quantity and the type of the alloying elements in TRIP-steels on the tendency for deformation induced martensite formation during plastic deformation.

2. Materials, methods and experimental results
Five austenite metastable steels with maximum propensity for martensite formation with compositions, corresponding to accepted standard labels according to EN BDS, given in Table 1 were studied. One of the steels is manganese as the others are additionally alloyed with chromium – 5 and 10% (weight) and with molybdenum and vanadium within the limits of 2%.

Table 1. Phase composition, mechanical properties and values of the coefficient K for the investigated alloys

<table>
<thead>
<tr>
<th>Steel designation-EN BDS</th>
<th>Phase composition after:</th>
<th>R\textsubscript{m}</th>
<th>R\textsubscript{0,2}</th>
<th>A\textsubscript{5}</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>quenching</td>
<td>Tensile stress test</td>
<td>MPa</td>
<td>MPa</td>
<td>%</td>
</tr>
<tr>
<td>1 \textsuperscript{1} X30Mn12</td>
<td>A + 20%Ms</td>
<td>A + 20%Ms +32Md</td>
<td>793</td>
<td>221</td>
<td>8,3</td>
</tr>
<tr>
<td>2 \textsuperscript{1} X30CrMn5.12</td>
<td>A</td>
<td>A + 56% Md</td>
<td>914</td>
<td>334</td>
<td>18</td>
</tr>
<tr>
<td>3 \textsuperscript{1} X30CrMn10.10</td>
<td>A</td>
<td>A + 50% Md</td>
<td>781</td>
<td>211</td>
<td>16,8</td>
</tr>
<tr>
<td>4 \textsuperscript{1} X30CrMnMo5.12.2</td>
<td>A</td>
<td>A + 52% Md</td>
<td>998</td>
<td>342</td>
<td>24</td>
</tr>
<tr>
<td>5 \textsuperscript{1} X30CrMnV5.12.1</td>
<td>A</td>
<td>A + 50% Md</td>
<td>887</td>
<td>322</td>
<td>15</td>
</tr>
</tbody>
</table>

Abbreviations: A – austenite, Ms – thermal martensite, Md – deformation martensite
Standard specimens for tensile stress tests of the investigated alloys were quenched in quartz ampoules (inert atmosphere) from 1150°C (30 min) in water. They were subjected to tensile stress test at ambient temperature till their destruction. With special magneto metric device [1] the concentrations of the deformation induced martensite in function with the plastic deformation degree were registered. The instrumentally derived dependencies are shown in Fig.1 whereas their phase composition, the maximum quantity of the deformation induced martensite and their mechanical properties are given in Table 1.

As it can be seen from Table 1, after quenching, the alloys(with the exception of steel No.1) have austenitic structure whereas the ones subjected to tensile stress test at ambient temperature till their destruction, formed between 50% and 56% deformation induced martensite. The coefficient K, given in Table 1, is the ratio of the maximum amount of martensite relative to the corresponding degree of maximum deformation at the moment at which the sample brakes. Practically, it reflects the average amount of deformation induced martensite that falls on 1% plastic deformation which can be formulated as the tendency of the alloy toward deformation martensite formation.

3. Discussion of experimental results

On the basis of the experimental results, the following can be said:

- The highest tendency to deformation martensite formation has carbon steels alloyed only with manganese of the type X30Mn12 – steel 1. The studies of other authors [2-6] show that in binary Fe-Mn alloys, the minimal stacking fault energy is observed at 12% concentration of the manganese [2]. It has also been found that TRIP-steels have the greatest propensity to martensite formation at a concentration of carbon of the order of 0.3 weight% [2-6]. For the investigated alloy 1% plastic deformation corresponds to 3.2% deformation induced martensite formed. Despite its high propensity for martensite formation, this steel is hard to find its application. It has two phase structure-austenite and martensite. The martensite is thermal and has no deformational origin. For these steel minor deviations in its chemical composition or production technology lead to unpredictable changes in its phase composition, this is technically unacceptable.

- Presence of 5-10% (weight) chromium/steel – X30CrMn5.12 /leads to stabilizing of the austenite at ambient temperatures and prevents the formation of initial martensite but decreases the ability towards deformation induced martensite formation/coefficient K decreases/. From practical point of view the effect of chromium on the deformation martensite formation in these steels is positive despite the fact that it increases the SFE of the austenite. It was determined that 5% chromium are sufficient to significantly increase the mechanical properties of the steel and its plasticity.

- Increasing of the chromium contend from 5 to 10% (weight) /steel – X30CrMn10.10/ does not affect the alloy's inclination to deformation induced martensite formation. It does not affect the maximum amount of deformation induced martensite formed and does not increase its mechanical properties. Therefore, increasing the amount of chromium in the range above 5% is economically unprofitable.

- The results showed that the additional alloying of chromium-manganese steel with molybdenum steel X30CrMnMo5.12.2, Table 1, in the range of 2-3% (weight) does not lower considerably its tendency to deformation induced martensite formation and does not change the maximum amount of deformation martensite, formed in it. It has a particularly favourable effect on mechanical properties, greatly increasing the plasticity of the steel. Molybdenum is a weak carbide and nitride forming element and, after quenching, is present mainly in the solid solution. Thus, it positively affects its properties over a wider temperature range compared to other more strong carbide and nitride forming elements.
- Alloying of the TRIP-steels with vanadium steel X30CrMnV5.12.1, increases its ability towards martensite formation /K-2,8/ but decreases its mechanical properties and plasticity. Another characteristic result is that vanadium modifies the character of the dependence deformation martensite – deformation degree – Fig.1 as significantly increases its “incubation” period in terms of the deformation degree, probably due to the presence of insoluble vanadium Carbides along the grain boundaries.

![Graph](image.png)

**Fig.1. Dependence of deformation induced martensite quantities in function of the plastic deformation degree**

The type of relationships shown above for the amount of deformation martensite by the degree of deformation – Fig. 1, is distinguished from that of the anisothermal dependence on the formation of "thermal" martensite/ formed as consequence of the temperature change/ derived from our other researches. The thermal martensite is characterized with the absence of incubation period since the formation of thermal martensite has a heterogeneous and / or autocatalytic nature.

The deformation induced martensite shows an incubation period with respect to the applied deformation. This confirms the model and the theory of Olson G. and Cohen M. [7, 8], according to which the presence of an "incubation" period is associated with the formation of ε-martensite and α-nucleus of a size capable of growing spontaneously.

### 4. Conclusions

The results obtained led to the following main conclusions:

- The highest tendency to deformation induced martensite formation has carbon steels alloyed with manganese only.
- The presence of 5% (weight) chromium /alloys 1 and 2 /leads to stabilization of the austenite at room temperature, prevents the appearance of initial martensite and does not reduce its tendency to deformation martensite formation.
- Increasing of the chromium content up to 10% (weight) does not positively affect the maximum amount of deformation martensite formed and does not increase the mechanical properties of the alloys.
- The additional alloying of chromium-manganese alloys with molybdenum does not significantly reduce the inclination of the steel to deformation martensite formation and does not change the maximum amount of deformation martensite in them. It has a beneficial effect on the mechanical properties, greatly increasing the plasticity of the steel.
- Alloying of the TRIP-steels with vanadium increases their tendency to martensite formation, but it aggravates the mechanical properties and plasticity. Vanadium modifies the nature of the dependence: deformation induced martensite-deformation degree, significantly increasing the "incubation" period in terms of deformation.

Acknowledgements
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References
Ageing of Solid Rocket Propellants Investigated by Ultrasound Technique

Borislav GENOV¹, Dimitar KIRKOV¹, Mitko MIHOVSKI², Yordan MIRCHEV²

¹ Department of Development of Armament, Technics and Materials, Defence Institute, Sofia, Bulgaria
Phone: +359 2 9221850, Fax: +359 2 9221808; e-mail: b.genov@di.mod.bg
² Institute of Mechanics at the Bulgarian Academy of Sciences, Block 4, Acad. G. Bonchev Str., 1113 Sofia, Bulgaria
Phone: +359 2 9797120; e-mail: mirchev@imbm.bas.bg, mntdd@abv.bg.

Abstract.
The goal of service life assessment of munitions is to provide the most reliable and most accurate prediction of service life possible in support of assuring safety, mission performance, and effective cost. Two parallel paths are generally followed for a continuing assessment of service life. Two paths is available – analytical and surveillance. The first one assesses the rate of aging, the effect of aging on the system level (i.e., stability, performance, integrity, etc.) and the statistical probability of system failure during service life. The second path incorporates system observation and system trend analysis.

In striving to attain the goal of service life assessment of munitions the destructive methods is the best existing tool, characterized by partial or full destruction of these expensive products. Mostly, the received information from such a testing is not fully reliable and appropriate for accurate prognosis for age life.

The nondestructive methods are powerful tools in many industry areas, but not so popular for ammunition qualification. However several nondestructive methods exist – radiation, visual, microwave and other techniques. The ultrasound techniques are not so popular during qualification of ammunition for service use, except bond-line integrity of propellant and insulation.

The objective of this work is to develop ultrasound method as an auxiliary tool for estimation of life cycle period for solid propellants for missiles is proposed. Several artificial aged samples are investigated by 2 and 4 MHz sensors.

Good correlations between ultrasound velocity and age of solid propellants were found. These relations could be used as an additional information for prognosis for age life.

Keywords: Ultrasonic Pulse Echo; Rocket Propellants

Introduction

Solid propellant systems for rockets are designed to function within narrow performance boundaries, sometimes after several times extended shelf life. In order to guarantee these performances we must be able to predict their performance during age, as well as determine their residual life span after the system has been subject to handling and storage under varying conditions which are not always fully recorded.

Service life assessment begins in the development phase and monitoring programs must be developed and implemented during the life span of the system.

The two interacting iteratively paths to produce current service life estimates are used [4]. One path is analytical which assesses the rate of material aging, the effect of material aging on the system (i.e., stability, performance, integrity, etc.) and the statistical probability of system failure during service life. The second path is one of system surveillance (monitoring) which includes system observation and system trend analysis. As a result, the service life estimate may predict a minimum service life (safe interval) that will likely be extended on testing at a later period. All aspects of service life issues for solid rocket motor will be addressed including chemical and physical aging mechanisms, methodology and techniques for determining service life, application of the service life methodology and techniques to systems and non-destructive test methods. For these paths NATO is developing system of standards [5]. Unfortunately,
nevertheless of the approach used most of the tools provided information for these paths are destructive ones.

Generally, NDT methods are powerful tool for many industry areas, but due to their inherent limitations and complementary nature of different types, many of them need to be applied depending on their suitability as a service life estimation tool [2].

For inspection at various stages of its production and service life of the rocket motors for instance:
- NDT methods such as radiography, ultrasonic testing and dye-penetrant testing are being employed for the inspection of hardware,
- ultrasonic testing is applied for checking the bond-line integrity of case and insulation layer and
- X-ray radiography is employed for evaluating both the integrity of propellant mass and the bond-line integrity of propellant and insulation.

**Proposed ultrasound technique**

In this article ultrasound technique, based on different propagation velocities for different aged samples, is proposed. The velocity difference for similar other conditions is due to different absorption and dissipation of ultrasound waves.

In every case ultrasound waves attenuation (due to impedance, absorption, etc.) is hardly to express precisely [4]. For the absorption \( \alpha \) on the macro-level is valid the following [3]:

\[
\alpha = \frac{\omega^2}{2\rho_i V_i} \left[ \eta + \left( \frac{\Delta \lambda}{\lambda + 2\mu} \right) \frac{K}{C_y} \right] \tag{1}
\]

where:
- \( \Delta \lambda \) – the difference between isothermal and adiabatic Lame coefficients;
- \( V_i \) – velocity of ultrasound wave;
- \( \omega \) – frequency.

For thermoelastic losses, similarly to (1) we can write:

\[
\alpha = \frac{\Delta c}{2V} \cdot \frac{\omega^2 \tau_{th}}{1 + \omega^2 \tau_{th}^2} \tag{2}
\]

where:

\[
\tau_{th} = \frac{K}{C_p V^2}
\]

\( C_p \) – thermal capacity for constant pressure in volume.

Therefore:

\[
\alpha = \frac{\gamma_g^2 C_y T}{2 \rho V^2} \cdot \frac{\omega^2 \tau_{th}}{1 + \omega^2 \tau_{th}^2} \tag{3}
\]

where:

\[
\gamma_g = \frac{3\beta K}{C_y} \quad \text{– Gruneisen constant;}
\]

\( \beta \) – linear extension constant.

The viscosity corresponds to the so-called loss of Akhieser and is the result of a detailed calculation of the "phonon-phonon". The detailed calculations were performed in [14].
Here, the final equation is presented:

\[
\frac{\alpha}{f^2} = R\gamma_g^2
\]  

(4)

where:

- \(\gamma_g\) – modified Gruneisen constant;

\[
R \frac{K_{\Theta_p}}{M\Theta_p^3 V_0^{2/3}}
\]  

(4a)

where:

- \(K_{\Theta_p}\) – thermal conductivity coefficient for Debye temperature \(\Theta_p\);
- \(M\) – molecular weight;
- \(V_0\) – molecular volume.

The dissipation of ultrasound is depend mainly from different defects and reliable theory exist for materials with crystal lattice.

In this work this is not a case – similarly like [3, 13], here we use absolute or relative velocity variations.

**Experimentation and Results**

For experimentation three groups of samples are used. All the samples are originated from 40-year rocket propellants, that are artificially aged for 8 months, 3 years and 10 years (Table 1). The aging program used is according AOP-48 Ed. 2 [1]. Obviously, there are an infinite number of temperatures that can be used for accelerating the aging process. It would be nice to say that the temperature selected was based on some highly quantifiable and/or scientific basis. The reality is that the temperature used is based on two very non-scientific reasons:

- the time available to conduct the ageing and,
- available funding.

The samples are finished to provide paralelism and roughness \(R_a<6.3\ \mu m\).

The classic contact ultrasound technique is used based on time of transit of a longitudinal ultrasound wave through the testpiece from the entrance point at the transducer to the exit point at the transducer. The 2MHz and 4MHz transducers are used.

The results showed that dependence between ultrasound waves velocity and age of samples exist.

This dependence is more clear for 4 MHz, that could be expressed with the relation of the sensitivity of the method with the frequency [2].

**Table 1 Description of the samples groups**

<table>
<thead>
<tr>
<th>Samples groups</th>
<th>Samples age</th>
<th>Expected life spans</th>
<th>Average sample height, mm</th>
<th>Velocity of ultrasound wave</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Samples group 1</strong></td>
<td>40,7 years</td>
<td>9,3 years</td>
<td>11,713</td>
<td>1949,9</td>
</tr>
<tr>
<td><strong>Samples group 2</strong></td>
<td>43 years</td>
<td>7 years</td>
<td>11,72</td>
<td>1945,2</td>
</tr>
<tr>
<td><strong>Samples group 3</strong></td>
<td>50 years</td>
<td>none</td>
<td>11,727</td>
<td>1912,5</td>
</tr>
</tbody>
</table>

With Table Curve 2D the following dependencies have been obtained between the service life and the ultrasound wave propagation rates (Fig. 1):
Fig. 1. Dependencies between the service life and the ultrasound wave propagation rates

The proposed these that the greater attenuation in samples with longer service life is proofed on the micro-level with the electronic scanning technique. For longer serviced samples (43 and 50 years) the more structural changes are found – micro and macro cracks, rounding and sharpening due to stabilizer and binders depletion and mechanical and temperature stresses during service life.

Fig. 2. “Sharpening” and “rounding”
Conclusion

The ultrasound technique is proposed as an additional tool in existing system of standards for service life qualification of rocket propellants. The method is partially proof for propellants include nitrate esters on micro level by electronic scanning microscopy. The future verification within the framework of more complex program is needed to develop the method to tool for prognosis of residual service life of explosives elements.

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Quantum-Mechanical Uncertainty in NDT
(Example of Scanning Tunnel Microscopy)

Roman SHULYAKOVSKY, Alexander GARKUN, Michael LEVCHUK, Maxim NEVMERZHITSKY, Alexei SHAPLOV
Institute of Applied Physics, National Academy of Sciences of Belarus, Minsk, Belarus
Phone: +375 17 284 17 94, Fax: + 375 17 284 17 94; e-mail: shulyakovsky@iaph.bas-net.by

Abstract
Nanodiagnostics is one of the most promising scientific directions of NDT. The greatest development of nanodiagnostic systems occurs with the use of scanning probe microscopy (SPM). In this paper we will try to estimate applicability of existing approaches to modern high-quality STM which characterized by high resolution and very small distance between probe and object (up to units Å or even less). It is shown, that standard semi-classical approximation does not work in many interesting cases. Instanton method for the calculation and estimation of tunneling processes for STM is proposed.

Keywords: Nanodiagnostics, scanning probe microscopy, tunneling, Fowler – Nordheim formula, instanton.

1. Introduction

As Academician Vladimir Kluev said “One of the main ways of developing of methods and facilities of nondestructive testing of the new generation is the use of known nanoeffects and nanosensors and nanotransformers developed on the basis of nanotechnology“ [1]. Nanodiagnostics is one of the most promising scientific directions of NDT. The greatest development of nanodiagnostic systems occurs with the use of scanning probe microscopy (SPM).

The first historical example of SPM is scanning tunneling microscope (STM), which was created in 1982 by G. Binnig and H. Rohrer (Nobel Prize in Physics 1986 “for their design of the scanning tunneling microscope”) /together with E. Ruska "for his fundamental work in electron optics, and for the design of the first electron microscope"/. Theoretical background of STM based on a possibility of electron emission in intense electric fields from cold metal [2]. This process can be explained by the tunnelling effect, which was explained by George Gamow [3].

Tunnelling effect is essentially quantum-mechanical phenomena. It allows justification by means of quantum-mechanical uncertainty relation (Heisenberg uncertainty relation). Because of this quantum-mechanical particle (for example electron) can penetrate through the classically forbidden area (potential barrier). The most calculation of the effect was carried out in so-called quasiclassical approximation, which can be used for relatively small energies and large potential barriers (as for instance in [2]). But these conditions are violated often for the modern STM. In this paper we will try to estimate applicability of existing approaches to modern high-quality STM which characterized by high resolution and very small distance between probe and object (up to units Å or even less).

2. Characteristics and Parameters of a Scanning Tunneling Microscope

The main characteristic is tunnelling current (or current of electron emission) $J$: 

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\[ J \approx enD S, \]  

where \( e \) is electron charge, \( n \approx 10^{28} \text{ m}^{-3} \) – typical conduction electron density, \( v \approx 10^6 \text{ m/s} \) – velocity of electrons, \( S \) is a square of tunnelling contact (up to \( 10^{-19} \text{ m}^2 \)). The main quantity \( D \), probability of tunnelling transition, is given by the following expression:

\[
D(E) \approx \exp \left[ -2 \sqrt{\frac{2ma^2(U_0 - E)}{\hbar^2}} \right],
\]

where \( h \) – Plank constant, \( m \) – electron mass, \( U_0 \) and \( E \) are height of energy barrier and electron energy correspondingly (\( U_0 - E \) is so-called electron work function). And the main parameter in this context \( a \) is width of potential barrier or distance between probe and surface of conductive sample.

So, because \( e, n, v \) and \( S \) are practically given, the measurement of current \( J \) gives the quantity of distance between probe and surface and vice versa. This is the main physical principle of SPM work. Of course, the technical detail of mechanical scanning of surface is critically important. But the critical analysis of (2) is important first of all.

3. Probability of Tunnelling Processes in Quasi-classical Approximation and its Applicability for STM

Violation of Fowler-Nordheim formula for the autoemission current in real experiment was already discussed (see for instance [4]). We see the possible reason in incorrect using of (2) in real experimental facilities.

Let us remind several simple quantum-mechanical tasks and consider for instance standard ("student") potential (fig.1, left).

![Fig.1. Rectangular potential barrier, energy of the particle \( E < U_0 \) (left). The dependence of pre-exponential factor on energy ratio (right).](image)

The decision in quasi-classical approximation is given by well-known formula:
This expression is very similar to (2) with the exception of pre-exponential factor. Here we pay attention, it is not equal to unit even approximately (see fig.1, right) and can be carefully taken into account.

Expression (3) can be applicable for “large“ potential barrier and “low” electron energies. By the way, these conditions are not applicable in general case in modern STM schemes. The exact solution for probability of barrier penetration is well-known:

\[
D(E) \approx \frac{16E(U_0-E)}{U_0^2} \exp \left[-2 \sqrt{\frac{2m a^2(U_0-E)}{\hbar^2}} \right] \ll 1, \quad \frac{ma^2(U_0-E)}{\hbar^2} \gg 1.
\] (3)

But, as we know, this expression is used very rarely for solved considered tasks.

We can see (see below some differences between semi-classical (3) and exact (4) for different cases, fig.2), that taken into account of pure quantum (in sense not semi-classical expressions) effects can be critical for 0.1 nm (atomic size) and essential for 0.3 nm. One can consider more realistic (not rectangular) potential for the process of cold electron emission in electric fields. In our opinion it does not matter (see fig.3).

4. Conclusion

It is very important that it is essentially quantum effect, which can be possible due to quantum-mechanical uncertainty relations (Heisenberg uncertainty relations):

\[
\Delta p \Delta x \geq \hbar/2
\] (5)

\[
\Delta E \Delta t \geq \hbar
\] (6)

where uncertainties are given by formulas

\[
\Delta p = \sqrt{\langle p^2 \rangle - \langle p \rangle^2}.
\] (7)

Thus, we think, that the effect of quantum-mechanical uncertainty in NDT will be studied more carefully.

Of course, Fowler–Nordheim formula is more approximate to the real potentials and has been refined many times, but quantum aspects didn’t take into account carefully every time.

There is very strong method for the calculation and estimation of tunneling processes. This is so-called instanton method. It based on analysis of the classical calculation in imaginary time(see for example [5]). Some results can be found in [6].
Fig. 2. The dependence of coefficient of barrier penetration $D(E)$ on different parameters (exact solution and semi-classical approximation).
Our estimations and discussions in no way diminish role of the developers and creators of scanning probe microscopy, but only underscore their crucial role in the development of nanotechnology.

References

Immersion Measurement of Laser-Induced Ultrasound in Plastics

Victor V. KOZHUSHKO¹, Vladimir P. SERGIENKO¹, Yordan MIRCHEV², Alexander ALEXIEV²

¹ V. A. Belyi Metal-Polymer Research Institute of National Academy of Sciences of Belarus”, Kirov 32a street, Gomel, 246050, Republic of Belarus, E-mail: info@laser-ultrasound.ru
² Institute of Mechanics at the Bulgarian Academy of Sciences, Block 4, Acad. G. Bonchev Str., 1113 Sofia, Bulgaria
Phone: +359 2 9797120; e-mail: mirchev@imbm.bas.bg

Abstract.
The paper considers measurement of laser-induced ultrasound in plastic plate immersed in water by piezoelectric thin film transducer based on polyvinilidenfluoride. The electrical signal induced on the electrodes of the detector is amplified by means of two types of amplifiers. The first amplifier operates in «voltage» detection mode, where the signal is proportional to the time profile of pressure pulse, while the second type of amplifier operates in «current» detection mode, where the signal is proportional to the time derivative of the pressure pulse. The comparisons of time profiles and spectra of signals are presented.

Keywords: Laser-Induced Ultrasound; Polyvinilidenfluoride

Introduction

The applications of ultrasonic technique for evaluation of elastic properties of the materials are topical issue. The broader spectrum and shorter pressure pulses possess some advantages for diagnostics. Optoacoustic conversion implies an excitation of the ultrasound by nanosecond laser pulses [1]. The laser-induced probe acoustic pulse demonstrates expressed compression phase while duration is comparable with the duration of the laser pulse. The spot of the laser radiation on the absorbing material defines the efficiency of excitation of different elastic modes such as longitudinal, shear and surface acoustic waves. The excitation of longitudinal pulses by wide laser spot in the plate is the simplest case, which can be considered in one-dimensional approach for evaluation of elastic modulus by primary waves. The probe pulse arrives to the opposite side of the plate and can be detected by variety of methods, which demonstrate some advantages and disadvantages [2]. The following echoes of the primary pulse can be detected for the estimation of velocity and attenuation of the longitudinal waves in broadband. The spectra of sequences of the pulses are getting narrower during the propagation these changes contain the information about microstructure and inhomogeneities such as, for instance, length of dislocations, their density and mean values grain size in metals. The absorption of the ultrasound in plastics are mainly due to the viscoelastic phenomenon.

Piezoelectric detection is the most widely used in ultrasonic diagnostics. It is assumed that the excitation of ultrasound is carried out by laser pulse that simplifies general task and requires only the proper detection of the probe ultrasonic pulse. In general case the circuits of preamplifiers are used to increase the electrical signal. The circuit of the preamplifier defines the operating mode. There are two established approaches for the sensors the first scheme is 'short circuit' or 'current' detection mode, where the low impedance resistor of about 50 Ohms is in parallel to the capacitance of the sensor and condition $R < 1/\omega C$ is fulfilled. The 'short circuit' mode allows detection of high frequency part of the induced pulse spectrum while 'voltage' mode is working in the narrower band because of the slower charge flow. The high frequency limit of the operating bandwidth should satisfy the condition $f < 1/T$ in the 'short
circuits'. A calculated time constant of \( \sim 3.8 \) ns allows the detection of the frequencies up to 200 MHz. The current across the resistor according to the Ohm's law is as:

\[
\frac{dq(t)}{dt} = \frac{U}{R}.
\]  

(1)

The displaced charge is proportional to the instantaneous mean stress inside the film that can be written as follows [3]:

\[
q(t) = A \frac{d_{33}}{h} \int_{0}^{h} P(x, t) dx,
\]  

(2)

where \( d_{33} \) is the piezoelectric charge constant, \( A \) is the area of the sensor, \( h \) is the thickness of the foil, \( P(x, t) \) is the pressure field including counter propagating waves reflected by backing material. This pressure field depends on the thickness of the covering protective aluminum foil and the acoustical impedances of all materials.

The calculation of the voltage yields the following expression:

\[
U(t) = R \frac{d}{dt} \left( \frac{d_{33} A}{h} \int_{0}^{h} P(x, t) dx \right).
\]  

(3)

The expression shows that the voltage drop signal is proportional to the area of the sensor that is true if the pressure pulse with the plane wavefront covers the larger area of piezoelectric film then the stronger current flows through the resistor. The proportionality to the value of the resistor increases the sensitivity with the decreasing of the bandwidth. It is noteworthy that measured signal is proportional to the derivative of the pressure profile over time that highlights the inefficiency of the 'short circuit' or 'current' mode for the measurement of the slow variations or the signals composed by low frequencies. The opposite situation is in the case of voltage detection mode where the low frequencies are conserved but high frequencies fast decay [4].

The high impedance resistor placed in parallel to the capacitor of the sensor increases the sensitivity in the low frequency range and omits the high frequencies. The simplest and limit case of infinite impedance of sensor leads to the following expression:

\[
U(t) = R \frac{d}{dt} \int_{0}^{h} P(x, t) dx.
\]
\[ U(t) = \frac{q(t)}{C_s} = g_{33} \int_0^h P(x, t) \, dx \]  

(4)

As the charge and capacity are proportional to the area the expression (4) shows that voltage dependence mainly proportional to the integral value of the pressure over the thickness. The time dependence gives also some integrated pressure value in comparison with 'current' detection mode.

**Results**

The experimental setup employs laser LOTIS Tii model LS-2131M-10 operating on the wavelength of 532 nm in Q-switch mode with pulse energy about 10 mJ and duration of pulse about 10 ns. The size of the laser spot on the plastic surface was about 5 mm diameter. The plate of black ABS plastic with the thickness of 3.8 mm was illuminated by laser radiation. The detection of the ultrasound was carried out from the opposite side of the specimen by piezoelectric transducer based on 25 µm thick polarized PVDF film. The diameter of the sensitive element is 2 mm. The preamplifiers were connected to the transducer via coaxial cable. The electrical signals were measured by digital oscilloscope with bandwidth of 200 MHz and 1 GHz sampling rate. The moment of laser pulse excitation was detected by PIN photodiode Hamamatsu S5971-1.

The free side of the specimen was illuminated by laser pulse, while the opposite side was in contact with 2 mm thick water layer which provided acoustical contact between specimen and transducer. The transducer was connected to one of the preamplifiers. The signals separately obtained by two preamplifiers are presented in the Fig.2. The peak-to-peak amplitude of amplifier operating in 'Voltage' detection mode is at least 3.5 times higher in comparison with the signal obtained in 'Current' detection mode. The laser power density was kept for both measurements. The spectra of the signals are in the Fig.3. The dynamic range is about 40 dB for each case but the sensitivity to the low frequencies is higher in the case of 'Voltage' detection mode that is in agreement with calculations.

![Fig.2. Signals detected by transducer with preamplifiers operating in voltage and current detection modes](image-url)
Conclusions

The features of piezoelectric detection of laser-induced ultrasonic pulses are considered. Sensors can measure longitudinal ultrasonic pulses by immersion technique both in the metals and in the polymer composites. There are two types of preamplifiers’ circuits for broadband piezoelectric sensors based on 25 μm thick PVDF film. The broadband detection of the frequencies in the range from 2 to 15 MHz requires low value resistor in parallel to the capacity of the sensor that is called 'short circuit' or 'current' detection mode where the measured signal is proportional to the time derivative of the mean pressure field in PVDF film. The 'voltage' mode allows to increase sensitivity in the low frequency bandwidth up to 15 MHz.

References

Module for Diagnostics and Analysis of Metal Archaeological Artefacts

Diana P. PETROVA, Dimitar NEDELCHEV

Technical University of Varna, Bulgaria
e-mails: dpetrova@tu-varna.bg, d_nedelchew@mail.bg

Abstract
More and more often, non-destructive methods of exploration have been applied in the search for archeological values, which is indispensable in terms of their uniqueness and preservation in the form in which they are found. This necessitates the creation of a module that makes it easy and accessible to diagnose and analyze artifacts. This paper provides a module for diagnosis and analysis of copper, tin, lead and other findings.

Keywords: Laser product analysis, roentgen analysis, metal archaeological artefacts, module, utensils, copper, bronze

Модул за диагностика и анализ на метални археологически артефакти

Диана. П. ПЕТРОВА, Димитър НЕДЕЛЧЕВ

1. Въведение

Въпросите за възникването на металообработването по българските земи в миналото заема важна част в някои интердисциплинарни изследвания. В историческата и най-вече в археологическата книжнина има редица различни анализи, хипотези и теории. В тази връзка, провеждането на изследвания – металографски, спектрални и рентгено флуоресцентни, биха могли да дадат отговори за началото на металообработката, технологията за изработка и състава на използваните метали [1]. Важно е да се отбележи също, че споменатите методи не разрушават изследваните предмети.

Накратко описаното предполага създаването на лесен и достъпен модул за диагностициране и анализиране на археологически артефакти. От направеното проучване на екипа, става ясно, че няма данни за такъв модул за диагностициране на движими и недвижими културни ценности.

2. Модул за диагностика и анализ на метални археологически артефакти

Модулът за диагностика и анализ на метални археологически артефакти съдържа няколко раздела: входна информация за находката, описание на проведените изследвания и резултатите от тях, обработка и анализ на получените резултати, сравнение на получените резултати с аналогични образци, обобщение, изводи и заключение.
2.1. Входна информация:

Разделът „Входна информация“ обхваща:
- наименование на находката – например инструмент, матрица, калъп, лампа, съд и пр. [2]. Ако изследваната находка не е изцяло запазена, то тя се определя като „част“ или „фрагмент“ от цялото (латинското: *Pars pro toto*, което е равно на “a part (taken) for the whole”);
- описание – описание на външните белези, размери, тегло, описание на изображения, графични орнаменти и пр.;
- местонахождение – географско местонахождение на обекта, в който е открита находката;
- характеристики на обекта, включително неговия произход – например: Тракийски култов център; Римски град; Късноантична крепост; средновековно селище и пр.;
- произход – определен на база на археологически и сравнителни данни (важно за общата датировка на находката);
- период от време, за който се отнася находката.

В таблица 1 е показан пример за описание на бронзова находка, матрица, намерена в околностите на с. Бозвелийско, Варненско (фиг.1.) [3].

Табл. 1. Пример за описание на находка

<table>
<thead>
<tr>
<th>№</th>
<th>Характеристика</th>
<th>Информация</th>
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</thead>
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<td>1</td>
<td>Наименование</td>
<td>Матрица, бронз</td>
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<td>2</td>
<td>Описание</td>
<td>Масивна, плоска отзад, с почти правилна кръгла форма. Върху лицевата и страна е представен в сравнително висок релеф конник в ход на дясно. Изображението е реалистично, но статично, а фигурите са представени непропорционално. Конят е мускулест, с къси крака, буйна грива, която се спуска на широки кичури, и дълга опашка. Представен е с вдигнат ляв крак и ясно очертани ремъци на амуницията му. Устата е отворена, около е анфас, а ухото – късо и изместено нагоре. Ездачът е с къса дреха с очертани къси ръкави и остро деколте. С дясната си, присвивайки тяло ръка държи две изобразени едно зад друго копия, чиито тръгълни върхове като че ли са поставени в предпазител. С лявата ръка (която не се вижда) ездачът държи отпуснатата юзда на коня. Главата на конника е в профил, косата е къса, права и очертана с насечки, а лицето е безбрадо. На краката си конникът има шпори, макар че не личат ботуши или обувки. Фонът на изображението не е много гладък, а под коня основата е изтъкната, което придава известна дълбочина на изображението. Самият релеф е много добре оформлен и по него личат всички подробности. Матрицата е изработена чрез отливане по въсъчен модел.</td>
</tr>
<tr>
<td>3</td>
<td>Местонахождение</td>
<td>Намерена в околностите на с. Бозвелийско, Варненско</td>
</tr>
<tr>
<td>4</td>
<td>Происход</td>
<td>Тракийска култура</td>
</tr>
<tr>
<td>5</td>
<td>Период от време</td>
<td>IV – III в. пр. Хр.</td>
</tr>
<tr>
<td>6</td>
<td>Снимки</td>
<td>&lt;линкове към файловете с изображения&gt;</td>
</tr>
<tr>
<td>7</td>
<td>Забележка</td>
<td></td>
</tr>
</tbody>
</table>

593
2.2. Изследвания:
Разделът „Изследвания“ съдържа описание на:
- външни белези – патина (корозия), размери, форма, нарушение на целостта, характеристики на формата, състояние на повърхностния слой, износване, следи от обработка [4];
- химичен състав – описания на проведените изследвания на химичния състав [6], включително методът на изследване, мястото, откъдето са взети пробите [5] или местата на въздействие с диагностиращия уред;
- други изследвания, даващи допълнителна информация за произхода на обекта – структура, грапавост, микротвърдост.

2.3. Обработка на резултатите от изследването:
Този раздел обхваща:
- сравнение с аналогични артефакти по външни белези;
- сравнение с анализи на аналогични обекти;
- сравнение с база данни от евентуални находища на материала;
- сравняване с анализи по химичен състав - определяне на вида на материала на база външна информация; определяне на вида на сплавта на база съотношение на основните химически компоненти (пропорции на елементите от 5-100%); сравнение по съдържанието на допълнителни химически компоненти (1-5%); сравнение по "маркери" (0,1-1%).

Табл. 2. Пример на описание на химичния състав на находки

<table>
<thead>
<tr>
<th>№</th>
<th>Инв. номер</th>
<th>Находка</th>
<th>Химичен състав 5 - 100 %</th>
<th>Химичен състав 1 - 5 %</th>
<th>Химичен състав 0,1 - 1 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13376</td>
<td>Калъп</td>
<td>Pb 78,20</td>
<td>Fe 1,40</td>
<td>Zn 0,08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cu 18,20</td>
<td>Sn 1,54</td>
<td>Ir 0,64</td>
</tr>
<tr>
<td>2</td>
<td>3962</td>
<td>Калъп</td>
<td>Cu 59,88</td>
<td>As 1,07</td>
<td>Sb 0,23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sn 20,00</td>
<td></td>
<td>Nb 0,13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fe 0,27</td>
</tr>
<tr>
<td>3</td>
<td>4273</td>
<td>Калъп</td>
<td>Cu 56,14</td>
<td>Sn 1,53</td>
<td>Pb 0,21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Zn 42,83</td>
<td></td>
<td>Nb 0,25</td>
</tr>
</tbody>
</table>
В таблица 2. са показани примери за бронзови находки, калъпи, намерени в околностите на гр. Шумен и съхранявани в РИМ Шумен.

2.4. Обобщение, изводи и заключение:
Разделът съдържа обобщения, изводи и заключения относно произхода, периода от време, евентуални находища на материала, от който е изработена, технология на изработката, използвани приспособления и инструменти за нейното получаване.

3. Заключение
Модулът за диагностика и анализ на метални археологически артефакти създава възможност за компютърно обработване на информация за метални артефакти, включително търсене на анализи, съхраняване на информация, методики за изследване.

Литература
Заседание на Управителния съвет на EFNDT

Заседанието се състоя на 9 октомври 2018 г. в Брюксел. В заседанието, като член на УС на EFNDT, участва и изпълнителния директор на ННТДД, гл.ас. д-р Йордан Мирчев.

Заседанието бе ръководено от Председателя г-н R. Lion. Обсъдени бяха следните въпроси:
- Финансово състояние. Събиране на членския внос. Финансови резултати (положителни) от Европейската NDT конференция в Гьотеборг през 2018 г.
- Обсъдено бе сътрудничеството на EFNDT с: CEOC, Eurolab, ENIQ, EWF, ESIS и IAEA.
- По доклад на P. Trampus бе разгледано изпълнението на проект "Robotics for inspection and maintenance".
- Al. Mullin докладва, че окончателният вариант на стандарта EN ISO 9712 ще бъде завършен през 2019 година.
- Г-жа L. Dojcanova докладва за състоянието и проблемите на радиационната защита в съответствие с изискванията на IAEA.

Във WG1 е включена и Европейската федерация по заваряване (EWF) с цел разработване на подходи за обучение на инженери по заваряване извън EN ISO 9712.

Йордан Мирчев
Тържествена сесия на INDT Academy в рамките на 12th European Conference of NDT

10 годишнината на Академията се проведе на 13 юни 2018 г. в Швеция по време на 12 EC NDT. Участваха около 70 видни учени от цял свят в областта на БК и диагностиката.

Слово, посветено на годишнината, бе представено от основателя и председател Giuseppe Nardonì. Ключов докладчик беше Нобеловият лауреат по физика Carlo Rubbia. Той и европейският комисар Tibor Navracsics фокусираха внимание върху необходимостта от изследвания и иновации за енергетиката и околната среда.

В деловата част бяха представени изключително интересни доклади:
- Peter Trampus, Vjera Krstelj, Подготовка на задачи по БК за бакалавърски и магистърски степени в техническите вузове.
- Christian Boller, Първа докторска дисертация по БК в Дрезденския международен университет.
- Bernard Bigot, За новите атомни реактори.
- Yukiya Amano, Приносът на IAEA в изследванията и обучението по безопасност на хората и опазване на околната среда.
- Rainer Link, Индустрия 4.0. и мястото на NDT
- Uwe Ewert, Цифрова радиография
- R. Brisser, Участие на IAEA в научни изследвания и подготовка на кадри.
- Serge Dos Santos, Обработка на нелинейни сигнали (уъркшоп)

Генерална асамблея на INDT Academy
12-13.10.2018 г., Бреша (Италия)

По-важни моменти от програмата:

- Приветствие от Президента G. Nardoni;
- Доклад за финансовото състояние на Академията (P. Trampus);
- Обсъждане на промени в Устава;
- Доклад за 10 годишнината на Академията (V. Krstelj), представен на конференцията в Гьотеборг;
- Представяне на новите кандидати за членове на Академията: Younho Cho и Sajeesh Kumar Babu;
- Обсъждане в Университета в Пула на въпросите за интегриране на инженери в NDT;
- Организиране на десета работна среща на Академията през 2019 г. в Чехия.
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<td>2nd International Congress on Welding, Additive Manufacturing and associated non-destructive testing</td>
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