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PAINT COATINGS IN MILITARY APPLICATIONS GENERAL CHARACTERISTICS

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Abstract: The article presents an overview of research conducted on the development of camouflage coating systems in the range of ultraviolet, visible, near infrared and radar waves, as well as operational tests of these systems. Among other things, the influence of temperature on coating systems and tests in chambers with cyclically changing conditions is presented.
Keywords: camouflage, paint coatings, radar waves, corrosion resistance, military coatings.

1. INTRODUCTION

Polymer coatings are part of the system: surroundings - coating - substrate. Coating protects the substrate against the destructive influence of operating environment factors. In many cases, the coating determines the safe operation of a technical facility. Polymer coatings are applied to various types of substrates such as metals, wood, concrete, plastics, ceramics in order to protect the substrate against the effects of external factors (mechanical, chemical, environmental, thermal and other) and to give these substrates appropriate decorative and specific properties depending on destination. In most applications, the main purpose of polymer coatings is to protect the substrate against corrosion. The coatings are intended to significantly extend the service life of the protected substrate. Due to their different purposes, they have various structures. Figure 1 shows the structure of a typical multi-layer coating system (Radek, 2023).
Polymer coatings are obtained by applying, among others: paint materials. Paint materials are complex mixtures whose ingredients can be classified into four main groups (Kotnarowska, 2010). Figure 2 shows an example of the composition and proportions of typical components of the paint material.
In military technology, depending on the type of armed forces and purpose, paint coating systems of various structures and purposes are used. These systems have different functions. The basic functions include:

- protection of equipment against corrosion
- protection against changing weather conditions
- protection against solar radiation
- protection against sea water.

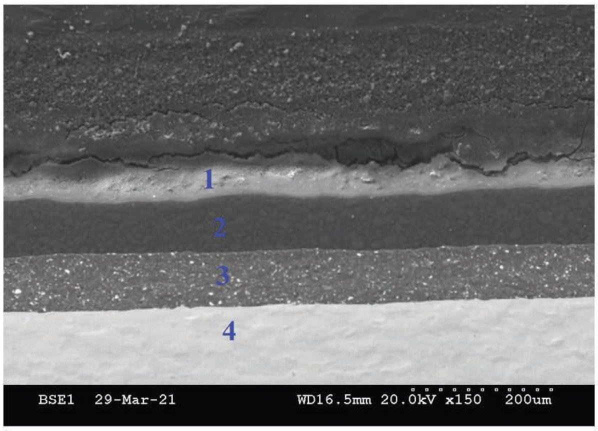


Fig. 1. SEM microphotography of the typical coating system on S355 carbon steel substrate: 1- topcoat, 2 – Inter coat, 3 – primer coat, 4 – steel (S355). Source: Radek N, 2023

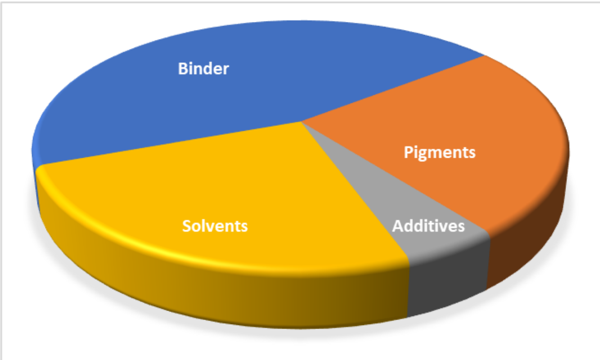


Fig. 2. Components and paint structure. Source: Kotnarowska D., 2010

Paint coating systems used in military technology also have other functions, including:

- resistance to aggressive media
- resistance to warfare agents and agents for eliminating contamination
- camouflage in the visible range and in a wider range of the electromagnetic radiation spectrum
- scratch resistance
- and other.

Modern camouflage coatings for military purposes bring innovative elements to other branches of industry, services, and research. On one hand, the military demand acts as an impetus for the development of materials and research techniques. On the other hand, it leads to the improvement of production techniques in civilian applications. This has resulted, for instance, in the creation of anti-graffiti coatings for railway rolling stock (Radek et al., 2019). This required achieving suitable corrosion resistance of the base material (Scendo et al., 2012), which was found to be linked to the effects of potentially shaping surface textures using laser technology (Scendo et al., 2013), also in specialized coatings applied through the electrospark deposition (ESD) method (Radek et al., 2008; Radek and Antoszewski, 2009), and DLC coatings (Radek et al., 2020; Radek et al., 2021). Surface smoothness also necessitates proper shaping of welded joints (Radek et al., 2018) and highly rough ESD coatings (Radek, 2009).

The coatings obtained, due to their high utility parameters, significantly impact the final product quality (Ulewicz, 2018; Pacana et al., 2021) and quality management methods (Borkowski et al., 2012). The complexity of processes requires the systematic application of Design of Experiments (DOE) methodology (Pietraszek et al., 2020) and appropriate training for the personnel involved in these processes (Radek et al., 2023).

2. CAMOUFLAGE

Camouflage is one of the most effective and at the same time more economical methods of hiding military equipment and thus gaining an offensive and defensive advantage over the enemy, both in defence and attack (Laprus M. 1979). Basic camouflage involves applying a coating system in the colour of the surrounding background. Camouflage works in the visible radiation range. Due to the development of sensors operating in a wider range of electromagnetic radiation, efforts are being made to achieve effective masking in the visible spectrum, ultraviolet, near infrared, radar waves operating in various bands and thermal imaging.

Research is being carried out on the use of new solutions to improve effective camouflage. Figure 3 shows the research conducted at the Military Institute of Engineering Technology on the EMCCO-4 material (Szczodrowska and Mazurczuk, 2021)

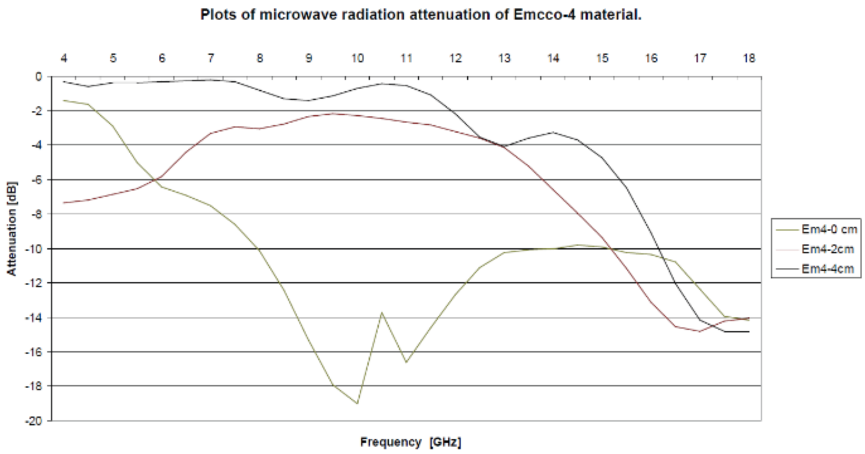


Fig. 3. Plots of microwave radiation attenuation of Emcco-4 material (own elaborators). Source: Szczodrowska B., Mazurczuk R. 2021

The graph shows that the attenuation properties reach below -18 dB for frequencies between 9 and 10 GHz. However, in the remaining frequency range the attenuation value is lower.

We can see similar results in tests using spherical iron (Radek N. 2023) presented in Figure 4.

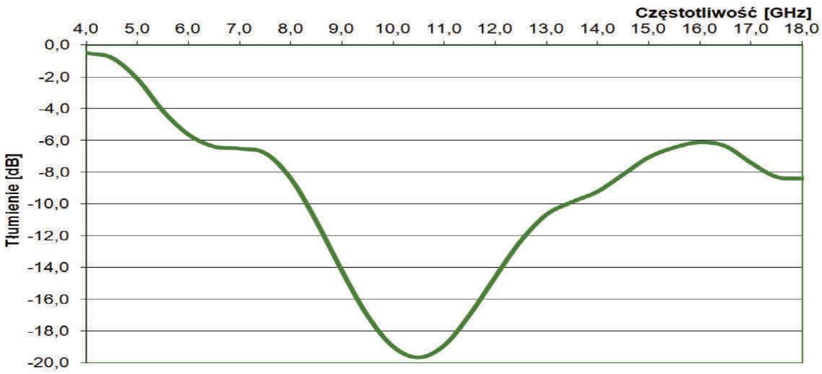


Fig. 4. Graphs of microwave radiation attenuation of SP5 material. Source: Radek N. 2023

The article (Huanzheng Z. et al., 2021) presents an example of multispectral camouflage for visible light, mid-infrared (MIR, 3-5 and 8-14 µm), lasers (1.55 and 10.6 µm) and microwaves (8- 12 GHz) with the possibility of cooling in a non-atmospheric window (5-8µm).
The results of this work may introduce the possibility of multispectral manipulation, signal processing and thermal management. Figure 5 shows the attenuation properties of radar waves in the range of 8-12 GHz.

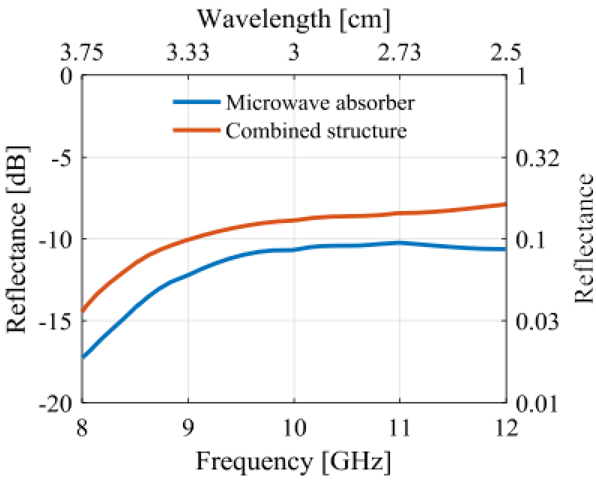


Fig. 5. Attenuation charts of microwave radiation of multispectral camouflage. (source: Huanzheng et al., 2021)

3. RESEARCH OF THE RESISTANCE OF CAMOUFLAGE COATING SYSTEMS TO VARIOUS EXPOSURES

3.1. Short-term exposure to temperature.

Camouflage coating systems used on vehicles and military equipment are subject to various exposures. They should be characterized by durable properties ensuring protection against the degradative impact of exposures such as: weather conditions, operating media, e.g. gasoline, diesel oil, grease, chemical agents and agents for eliminating contamination. The authors of the publication "The Influence of Operational Exposure on Changes in Parameters of Effective Camouflage of Coatings Used in Military Technology" present the aspect of short-term exposure of camouflage coatings to temperatures up to 250 °C. Camouflage paint system in three colour variants (green, brown, black), exposed to temperatures ranging from 90 °C to 250 °C changing every 20 °C. Table 1 shows the results of measuring the colour change in relation to the requirements of the defence standard.

Table 1
Change in ΔE relative to the defence standard for BW400-6031, BW400-8027, BW400-9021.

	90 °C	**110 °C**	**130 °C**	**150 °C**	**170 °C**	**190 °C**	**210 °C**	**230 °C**	**250 °C**
BW400-6031 (green) ΔE* in reference NO-80-A200	0,82	0,89	0,12	0,16	0,44	0,69	1,38	1,79	2,73
BW400-8027 (brown) ΔE* in reference NO-80-A200	0,98	0,97	0,93	0,88	0,89	0,92	0,90	1,08	1,79
BW400-9021 (black) ΔE* in reference NO-80-A200	0,90	0,53	0,88	0,94	1,34	0,49	1,05	0,62	0,43

Source: Michalski M. et al., 2023

Based on the obtained results, there was no influence of temperature in the above range on the colour change of the camouflage coating system.
In the next study, the influence of temperature on the change of colour coordinates of camouflage coating systems in the CIE L*a*b* system was checked for three colours: green, brown, black, which was presented in Figures 6 to 8.

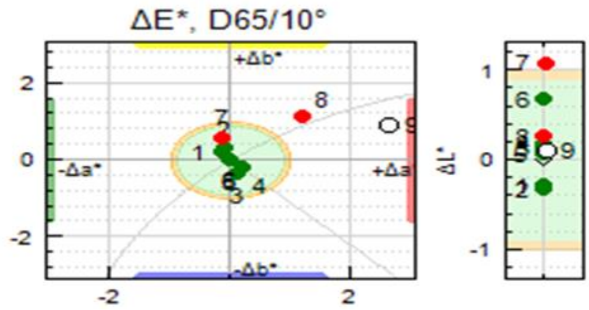


Fig. 6. Colour parameters for BW400-6031 (green). 1- 90 °C, 2- 110 °C, 3- 130 °C, 4- 150 °C, 5- 170 °C, 6- 190 °C, 7- 210 °C, 8- 230 °C, 9- 250 °C. (source: Michalski et al., 2023)

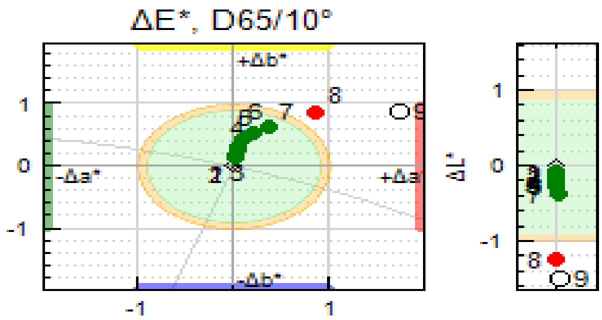


Fig. 7. Colour parameters for BW400-8027 (brown). 1- 90 °C, 2- 110 °C, 3- 130 °C, 4- 150 °C, 5- 170 °C, 6- 190 °C, 7- 210 °C, 8- 230 °C, 9- 250 °C. (source: Michalski et al., 2023)

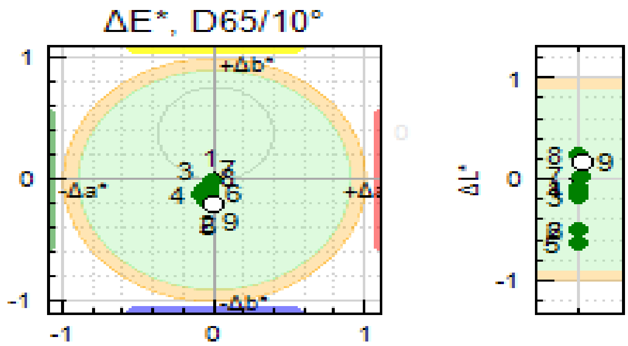


Fig. 8. Colour parameters for BW400-9021 (black). 1- 90 °C, 2- 110 °C, 3- 130 °C, 4- 150 °C, 5- 170 °C, 6- 190 °C, 7- 210 °C, 8- 230 °C, 9- 250 °C. (source: Michalski et al., 2023)

In the above figures you can see that the black colour is stable at temperatures up to 250°C, while the brown and green colours become more red and yellow.

The influence of temperature on the change in the spectral characteristics of the camouflage systems was also examined. Figure 9 shows the determined characteristics for the green colour.

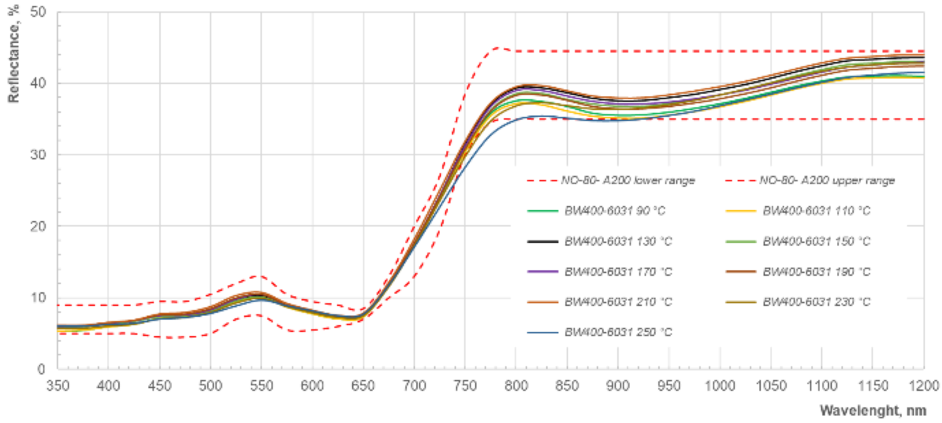


Fig. 10. Effect of temperatures from 90 °C to 250 °C on the reflectance of the BW400-6031 (green) camouflage paint coating system. (source: Michalski et al., 2023)

The determined spectral characteristics for coatings exposed to different temperatures did not show any significant differences.

3.2. EXPOSURE TO CYCLICALLY CHANGING CONDITIONS

The key aspect in selecting a camouflage coating system is its durability. It depends on a number of factors, such as: weather conditions, type of substrate used, method and conditions of surface preparation and application and drying of individual layers of the system. To assess the durability of coating paint systems taking into account environmental aspects, appropriate aging tests are used, which should be carried out in real time in various climatic zones. Testing coatings in natural conditions is a time-consuming process. This necessitates the use of accelerated artificial aging tests. It is worth noting that the simulated environment does not always correlate with the results obtained when exposing objects in natural conditions. However, accelerated artificial aging testing is essential for developing and improving coating products, but also for maintaining product quality throughout its life cycle.

The authors of the article "Operational tests of coating systems in military technology applications" present the results of cyclical aging tests conducted on a green camouflage coating system. The tests were carried out based on the PN-EN ISO 12944-6 standard. The cyclic test consisted of the stages shown in Figure 11. Stage one - test in a UV light chamber, stage two - test in a salt chamber and stage three - test at low temperature. The entire test lasts 7 days and can be repeated.

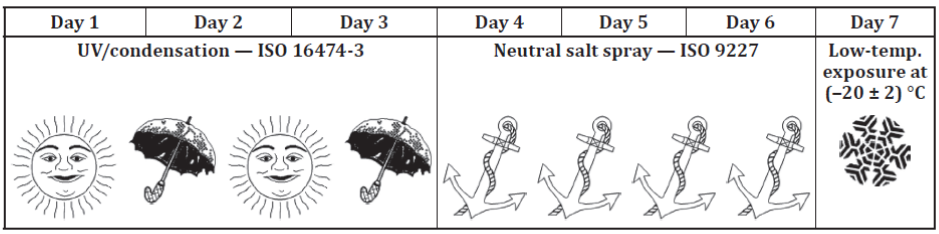
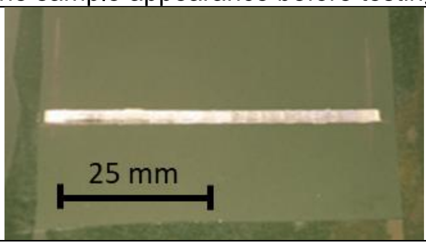
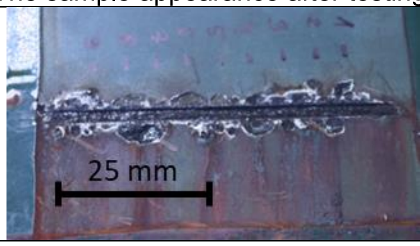


Fig. 11. Cyclic ageing test according to PN-EN ISO 12944-6 (Annex B)

Among other things, the impact of a cyclic aging test on gloss, colour and spectral characteristics was examined. Table 2 shows the results of coating destruction measurements and a photo of the coating before and after exposure.

Table 2

Results the camouflage coating system after the cyclic corrosion test according to PN-EN ISO 12944-6

Duration of exposure to cyclic climatic conditions [h]	2688
Resistance to cyclic climatic condition [h]	More than 2688
Degree of blistering	0 (S0)
Degree of rusting	Ri0
Degree of flaking	0 (S0)
Degree of cracking	0 (S0)
Degree of filiform corrosion	0 (S0)
Degree of corrosion around the scribe [mm]	2.4
The sample appearance before testing:	The sample appearance after testing:
	

(source: Radek et al., 2023)

Figure 12 shows changes in the spectral characteristics before and after exposure to changing climatic conditions.

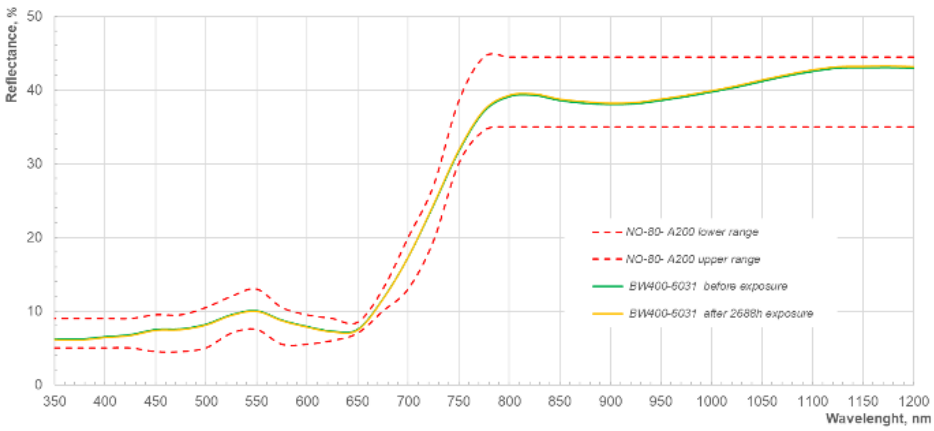


Fig. 12. Influence of cyclic changing climate conditions on the reflectance of BW400-6031 (green) camouflage coating. (source: Radek et al., 2023)

4. CONCLUSIONS

The implementation of new sensors for detecting and identifying military equipment forces the search for new solutions in the area of building camouflaging coating systems and their modifiers. When reviewing the literature, one can notice that research has been conducted in this area. This research covers a wide spectrum of electromagnetic radiation, from ultraviolet waves through near and far infrared, radar and thermal radiation. Some of these tests take into account the limitation of heating of coatings resulting from the close proximity of heating devices or solar radiation. The development of new solutions of coating systems creates the need to test not only the camouflage properties of a given coating system, but also the need to conduct operational tests of these systems using methods that most closely reflect the actual operating conditions of masking coating systems.

REFERENCES

Borkowski, S., Ulewicz, R., Selejdak, J., Konstanciak, M., Klimecka-Tatar, D., 2012. *The use of 3x3 matrix to evaluation of ribbed wire manufacturing technology*, METAL 2012 – 21st International Conference on Metallurgy and Materials, 1722-1728.

Huanzheng Z. et al., 2021. *Multispectral camouflage for infrared, visible, lasers and microwave with radiative cooling*. Nature Communications, 12, art. 1805. DOI: 10.1038/s41467-021-22051-0

Kotnarowska, D., 2010. *Powłoki ochronne*, Wydawnictwo Politechniki Radomskiej, Radom, Poland.

Lance C. Kelly, 2020. *Low-Emissivity Topcoats for the Reduction of Thermal Infrared Emissions from Military Platforms*, CoatingsTech, April 2020, 18-31.

Laprus M. *Leksykon wiedzy wojskowej*. Wydawnictwo MonI 1979.

Michalski M. et al., 2023. *The Influence of Operational Exposure on Changes in Parameters of Effective Camouflage of Coatings Used in Military Technology*, Advances in Science and Technology Research Journal, 17(1), 182-196. DOI: 10.12913/22998624/156940

Pacana, A., Czerwinska, K., Dwornicka, R., 2021. *Analysis of quality control efficiency in the automotive industry*, Transportation Research Procedia, 55, 691-698. DOI: 10.1016/j.trpro.2021.07.037

Pietraszek, J., Radek, N., Goroshko, A.V., 2020. *Challenges for the DOE methodology related to the introduction of Industry 4.0*, Production Engineering Archives, 26(4), 190-194. DOI: 10.30657/pea.2020.26.33

Radek, M., Pietraszek, A., Kozień, A., Radek, K., Pietraszek, J., 2023. *Matching Computational Tools to User Competence Levels in Education of Engineering Data Processing*, Materials Research Proceedings, 34, 453-459. DOI: 10.21741/9781644902691-52

Radek, N., 2009. *Determining the operational properties of steel beaters after electrospark deposition*, Eksploatacja i Niezawodnosc, 44(4), 10-16.

Radek N. 2023. *Powłoki do zastosowań w technice wojskowej technologie wytwarzania i właściwości*, Monogafia M160, 2023.

Radek, N., Antoszewski, B., 2009. *The influence of laser treatment on the properties of electro-spark deposited coatings*, Kovove Materialy, 47(1), 31-38.

Radek, N., Michalski, M., Mazurczuk, R., Szczodrowska, B., Plebankiewicz, I., Szczepaniak, M., 2023. *Operational tests of coating systems in military technology applications*, Eksploatacja i Niezawodnosc – Maintenance and Reliability, 25(1), art.12. DOI: 10.17531/ein.2023.1.12

Radek, N., Pietraszek, J., Goroshko, A., 2018. *The impact of laser welding parameters on the mechanical properties of the weld*, AIP Conference Proceedings, 2017, art.020025. DOI: 10.1063/1.5056288

Radek, N., Pietraszek, J., Pasieczynski, Ł., 2019. *Technology and application of anti-graffiti coating systems for rolling stock*, METAL 2019 – 28th Int. Conf. on Metallurgy and Materials, 1127-1132. DOI: 10.37904/metal.2019.909

Radek, N., Pietraszek, J., Szczotok, A., Fabian, P., Kalinowski, A., 2020. *Microstructure and tribological properties of DLC coatings*, Materials Research Proceedings, 17, 171-176. DOI: 10.21741/9781644901038-26

Radek, N., Tokar, D., Kalinowski, A., Pietraszek, J., 2021. *Influence of laser texturing on tribological properties of DLC coatings*, Production Engineering Archives, 27(2), 119-123. DOI: 10.30657/pea.2021.27.15

Radek, N., Wajs, E., Luchka, M., 2008. *The WC-Co electrospark alloying coatings modified by laser treatment*, Powder Metallurgy and Metal Ceramics, 47(3-4), 197-201. DOI: 10.1007/s11106-008-9005-7

Scendo, M., Radek, N., Trela, J., 2013. *Influence of laser treatment on the corrosive resistance of WC-Cu coating produced by electrospark deposition*, International Journal of Electrochemical Science, 8(7), 9264-9277.

Scendo, M., Trela, J., Radek, N., 2012. *Purine as an effective corrosion inhibitor for stainless steel in chloride acid solutions*, Corrosion Reviews, 30(1-2), 33-45. DOI: 10.1515/CORRREV-2011-0039

Suchart S., 2023. *A review on lightweight materials for defence applications: Present and future developments*, Defence Technology, 24, 1-17.

Szczodrowska B., Mazurczuk R., 2021. *A review of modern materials used in military camouflage within the radar frequency range,* Technical Transactions, 118, art. e2021003. DOI: 10.37705/TechTrans/e2021003

Ulewicz, R., 2018. *Outsorcing quality control in the automotive industry*, MATEC Web of Conf., 183, art.03001. DOI: 10.1051/matecconf/201818303001