Research on the Effectiveness of a Visual Protection of Military Objects in Field Conditions and in a Virtual Environment

PRZYBYŁ Wojciech[1a*], MAZURCZUK Robert[1b],
SZCZODROWSKA Bogusława[1c] and JANUSZKO Adam[1d]

[1]Military Institute of Engineer Technology, ul. Obornicka 136, 50-961 Wrocław, Poland

[a]przybyl@witi.wroc.pl, [b]mazurczuk.r@witi.wroc.pl, [c]szczodrowska@witi.wroc.pl,
[d]januszko@witi.wroc.pl

Keywords: Military Camouflage, Visual Protection, Field Conditions

Abstract: The article presents two methodologies for testing the effectiveness of camouflaging military equipment. The tested objects were camouflaged with deforming camouflage dedicated to the environment and season. The tests covered the visible spectrum and were carried out both in real conditions - training ground, and in a virtual environment – on a specially prepared calibrated stand, characterized by compliance with real conditions and human perception of vision – presented colors, as well as in terms of the amount of information and detail rendering. These two test methods were compared, attention was drawn to the high correlation of results and to some characteristic properties of both separately. The work confirms the legitimacy of developing and improving virtual research methods as supporting in the design and testing of modern camouflage patterns, especially at the initial stage of pattern design. It can also be useful when assessing masking systems in other ranges of electromagnetic radiation: UV, near infrared, or thermal range.

Introduction

Armed conflicts are an inseparable part of human history, but also the present and probably the future as well. Conducting military operations, both offensive and defensive, is associated with incurring huge costs, primarily social and material. However, one of the cheapest methods of protecting manpower and equipment are effective camouflage systems.

According to the definition [1] camouflage is a type of protection of combat operations, and consists in hiding forces and resources from recognizing the enemy or misleading him about the location of his own troops. Cloaking is therefore a broad issue (Fig.1) and depending on the level of command, it may concern the strategic, operational or direct (tactical) level. In turn, taking into account the means, forces or specifications used, we can distinguish concealment, presence or disinformation.

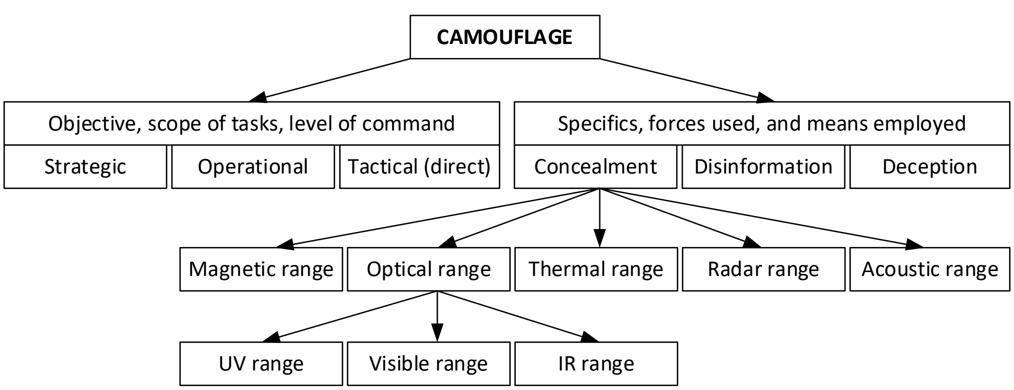

Fig.1. *Distribution of masking and its types (source: [2])*

New cloaking systems are constantly being developed and introduced, requiring the assessment of the effectiveness of the cloaking. In accordance with the above scheme, this article focuses on the verification of direct (tactical) camouflage in the context of concealment in the optical range, in particular in the visible range (Fig.2).

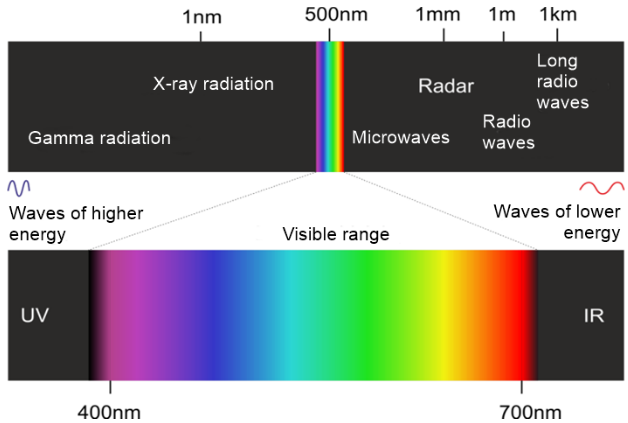

Fig.2. *Scheme of the spectrum of electromagnetic radiation*

Thus, the main task of effective camouflage is to eliminate the unmasking features, i.e. those that make it possible to distinguish one's own objects from the background of the terrain. In this respect, these are the differences in the patterns and colors of the spots forming the pattern of the background and the object, as well as the smoothness / dullness of the surface. For this purpose, camouflage patterns applied to military objects (equipment and equipment, vehicles, buildings, etc.) or uniforms are used [3].

In practice, it is difficult to obtain a universal camouflage that would suit any type of background: forest, desert, urban, winter, etc. Work on adaptive camouflage, which changes itself depending on the background, is carried out in many research centers, but meanwhile, beyond the laboratory level, they didn't come out. Therefore, in practice, camouflages dedicated to the appropriate type of object, background, and even the season of the year are widely used (Fig.3).

Fig.3. *Seasonal camouflage uniforms for Europe*

Within the types of patterns, a mimetic pattern is distinguished, which is to make it similar (mimicry) to the nearest background, and thus make it difficult for the observer to detect the object. However, patterns of this type do not break the silhouette, which makes it easy to recognize the object after detection, and thus to decide on the means of destruction used to destroy the object. Mimicry also does not ensure the continuity of colors and textures in the case of the movement of

Materials Research Proceedings 34 (2023) 380-389 https://doi.org/10.21741/9781644902691-44

the object. Therefore, in camouflage painting, especially on vehicles, deforming camouflage is also used, built on the basis of large spots in relatively high-contrast colors.

Investigation of Camouflage Effectiveness
The study of the effectiveness of masking consists in observing the background (edge) on which the object with camouflage (dedicated to the background) has been placed. A group of observers who should be experienced in recognizing military equipment takes part in the observations. The minimum number of observers is 3. During the tests, the degree of visibility of the object from the given distances is recorded. The degree of visibility is understood as a scale commonly used in reconnaissance:

- Lack (-) – no presence of an object of potential military importance in the observation area;
- Detection (W) – finding the presence of an object of potential military importance in the observation area – finding something that may be of interest to the observer;
- Recognition (R) – determination that the detected object is a specific type of object, e.g. a person, a wheeled armored personnel carrier, a tracked vehicle;
- Identification (I) – specifying that the recognized object is a specific type of object, e.g. a man is a soldier, a wheeled armored personnel carrier is APC "Rosomak", and a tracked vehicle is BPWP "Borsuk".

As part of this article, the study of the effectiveness of masking the type of object known to observers - the HMMWV wheeled vehicle (Fig.4) was carried out.

Fig.4. *HMMWV vehicle*

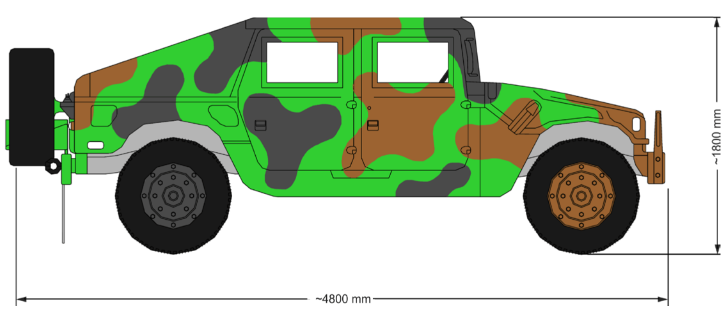

Fig.5. *Silhouette of the HMMWV vehicle in deforming camouflage (designed by WITI)*

For this purpose, a 1:1 scale model (silhouette) was used, made of steel sheet, covered with a camouflage pattern applied with special paints for camouflage painting in green, brown and black colors (Fig.5). Such an exemplary selection of colors and stains can be used in Central and Eastern Europe in the spring-summer-autumn season.

The tests were carried out for the scenery dedicated to this pattern - the background of deciduous, coniferous and mixed forests (woodland) in the spring-autumn period. The study was aimed at determining the effectiveness of masking in natural conditions in the most unfavorable situation for masking, and the most favorable for diagnosis. Therefore, the object was set on the outskirts of forests, on flat terrain, without obstacles to visibility (e.g. other vegetation), in a direction and direction that prevented the sun from blinding observers, and ensured good illumination of the object. It was also noted that the object should be visible in the range of at least ¾ of its height. The tests were carried out only on days without precipitation (fog, rain), at temperatures not causing air waves (vibrations) and with similar insolation conditions (cloudy sky) for each series [4].

The tests were carried out using two methods: in field conditions and in a virtual environment, and then the results were compared. The research methodologies were based on the Polish defense standard NO-80-A200 "*Special paints for camouflage painting. Requirements and test methods*" [5].

Field Trials

The object was placed on the edge of the forest in the selected and marked sector (outer) of observation. The observers did not know where the objects were located. They started the observations from a distance of 1,500 m. Within a maximum of two minutes, they determined the degree of object visibility (absence, detection, recognition) on the test cards. After this time, they approached 100 m closer to the object to re-determine the degree of visibility of the object. This procedure was carried out up to a distance of 500 m (Figure 6).

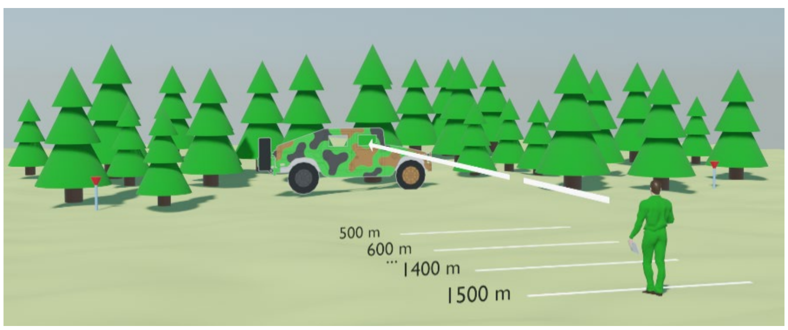

Fig.6. *Scheme of conducting field tests*

Virtual Environment

During the field tests, the terrain background was also imaged using the Canon EOS 50D Mark III camera (focal length 50 mm, matrix size 36×24 mm, resolution 3744 × 5616 – Table 1) at a scale of 1:10000 and a distance of 500 m (Fig.7).

The photos had to be characterized by appropriate parameters [6], to reflect the actual conditions as much as possible and include descriptive data (metadata) – Table 2

The tests in the virtual environment took place in a specially adapted room with limited access to external light sources and equipped with a multimedia projector, a screen and two positions – an observer and a research supervisor (Fig.8). To ensure the greatest color fidelity, the entire image path has been calibrated [7].

Fig.7. *An example image taken from a distance of 500 m during field tests*

Table 1. *Display parameters*

Focal length	Matrix dimensions		Resolution		Density	
	width	height	width	height	information	details
[mm]	[mm]	[mm]	[px]	[px]	[px/mm]	[mm/px]
50	36	24	5616	3744	156	0.01

Table 2. *Required display parameters*

Parameter	**Minimal value**	**Remark**
Spatial resolution	3600px × 2400px	Ensuring sufficient photo quality – avoiding the visibility of pixels in the presented photos
Total resolution	8 bit/channel	Ensuring sufficient total range
Color space	Adobe RGB	Ensuring a sufficient wide color space – presentation of as many colors as possible
File compression type	Lossless	Ensuring appropriate image quality – avoiding artifacts caused by lossy compression methods
White balance	Performing a white (grey) pattern	Ensure colour fidelity
Sharpness	Good resolution of details	Ensuring sufficient sharpness of the photo - presentation of the details of the photo also when the photo is enlarged
Exposure	Balance and full tonal range	Ensuring a wide tonal range for the examined background – distinguishing details for bright fragments, midtones and dart parts of the image
Location	Designation of the location of the imagery	Providing an indication of where the imagery was taken – either description or by geographical coordinates
Azimuth	Designation of the observed azimuth	Provides indication of the direction of the display
Date and time	Date and time stamp	Unambiguous and precise determination of the date and time of the imaging
Scenery	Possibility of specifying the scenery	Clear marking of the nature of the scenery (coniferous, deciduous, mixed forest, urbanized area, desert, demi-desert, rocky, steppe, etc.)
Season	Possibility to specify the season	Clear indication of the season (spring, summer, autumn, snowless winter, snowy winter, etc.)
Outline distance	Distance designation	Unique term to show the distance from the outskirts (background)
Lens focal	Focal length designation	An unambiguous indication of the focal length for the lens used to image
Color swatch	Image for color swatch	Increase in perceptual color fidelity for camouflage with palette matching with samples

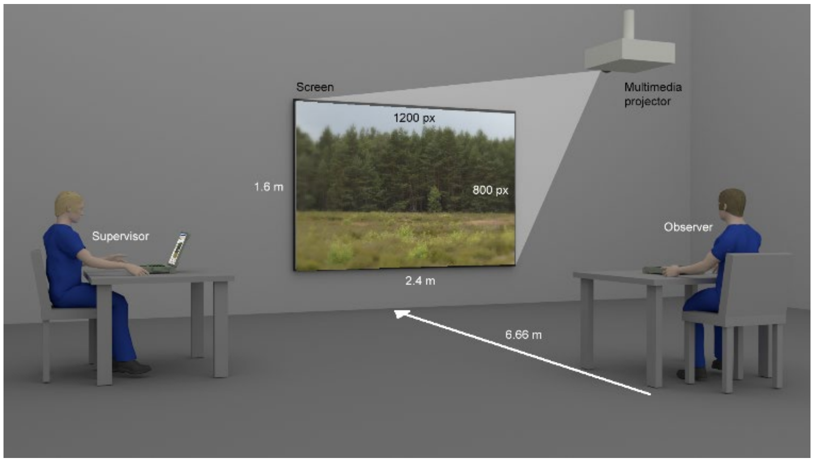

Fig.8. *Scheme of conducting research in a virtual environment*

Table 3. *Parameters of background fragments for example images 1:1000 (50mm focal length, 36×24mm matrix))*

Distance from the background	**Size of the background**		**Resolution**		**Density**	
	width	height	width	height	Information	details
[m]	[m]	[m]	[px]	[px]	[px/m]	[mm/px]
1000	360	240	5616	3744	7.8	124.2

Table 4. *Summary of observation results (OK indicates the agreement of the results of both methods, NOK indicates the discrepancy of the results of both methods)*

Trial No	Observer No	Field trials		Virtual trials*	
		distance W (detection)	distance R (recognition)	Detected at 1000 m	Recognized at 1000 m
1	1	1300	800	Yes (OK)	– (OK)
	2	1400	800	Yes (OK)	– (OK)
	3	1300	800	– (NOK)	– (OK)
2	1	1200	600	Yes (OK)	– (OK)
	2	1300	700	– (NOK)	– (OK)
	3	1200	600	Yes (OK)	– (OK)
3	1	1100	700	– (NOK)	– (OK)
	2	1100	600	– (NOK)	– (OK)
	3	1300	700	Yes (OK)	– (OK)
4	1	1000	800	Yes (OK)	– (OK)
	2	1000	800	Yes (OK)	– (OK)
	3	1000	800	Yes (OK)	– (OK)
5	1	600	500	– (OK)	– (OK)
	2	600	500	Yes (NOK)	– (OK)
	3	600	500	– (OK)	– (OK)
6	1	800	600	Yes (NOK)	– (OK)
	2	800	500	Yes (NOK)	– (OK)
	3	800	600	– (OK)	– (OK)
Average		**1022**	**661**	**11×W, 7×Null**	**–**

Materials Research Proceedings 34 (2023) 380-389 https://doi.org/10.21741/9781644902691-44

Taking into account the optical parameters of the camera [8] (focal length 50 mm, matrix size 36×24 mm, resolution 3744×5616), projector resolution (1200×800 px), screen size (2.4×1.6 m) and perceptual capabilities of the human sense of sight [9], it was established the distance of the observer to the screen at 6.67 m, which corresponded to the observation from 1000 m and provided enough information (pixels) to represent the scenery, while preventing the perception of the pixel nature of digital images displayed on the screen by the projector with a given resolution (Table 3).

The methodology of virtual research was based on the previously mentioned Polish defense standard and recommendations developed during the work of the NATO RTO-AG-SCI-095 working group [10]. In this method, the observers, also within 2 minutes, had to determine the degree of visibility of the object and, in order to verify the correctness, indicate the location of the object in the image. Table 4 contains test results for 6 tests carried out by 3 observers for each test in field conditions and in a virtual environment.

Conclusions

The results obtained by both methods are characterized by a high convergence of results. They were analyzed in terms of two degrees of object visibility – detection (W) and recognition (R). The scope of reconnaissance is a decisive factor, because usually in the course of combat operations, it is on its basis that decisions about further tactical or operational plans are made. Based on the results obtained for all tests and for each test, we can conclude that in the virtual method, an object with a deforming camouflage dedicated to woodland (special paints) was not recognized at a distance of 1000 m by observers using the unarmed eye. The results from field tests confirm this, because the recognition was carried out from a distance of 500 to 800 m (average 661 m), which is a distance of less than 1000 m. This means that the object, while approaching it, was later recognized.

On the other hand, in terms of detection (W), the results are mostly consistent (11 out of 18 trials), but for a few results there are discrepancies (5 out of 18 trials). Analyzing both test environments, it can be seen that during the tests in the real environment, the correctness of the detection cannot be verified, because as it turned out during the tests in the virtual environment, some observers incorrectly indicated the location of the object detection, which could be detected thanks to the laser pointer on the screen (and then the wrong detection is not counted), which was impossible to check during field tests. Another factor affecting the results could have been weather conditions, because despite conducting the research in the conditions recommended for the weather, some of its dynamics – slight wind, operation of the sun, shadows, or a wider range of perception affected the results. The availability of the observers themselves is also not without significance, as during laboratory tests they are not exposed to the inconvenience of field conditions – they make assessments in a comfortable position, without the need to move around, often in difficult training ground, being influenced by weather conditions. Summing up, it should be considered:

– studies in a virtual environment are largely consistent with environmental studies;
– research in a virtual environment, especially at the initial stage of designing and checking the effectiveness of masking, can give reliable results;
– both research methods should be further developed, e.g. in the virtual method, the perceptual compatibilityp with the natural environment should be deepened, and in the field method, an element verifying the correctness of the detected object should be added.

Optical military camouflage has a purely utilitarian character, although many of its elements can find applications beyond the military context. This particularly applies to clothing aspects, where quasi-military attire enjoys significant popularity among youth and survival enthusiasts. It also extends to the automotive and railway industries, as it provides the opportunity to enhance the quality of products [11-13] by skillfully optically masking geometric imperfections. Specifically, this relates to the surface of sheet metal, especially in the case of railway wagons [14], which require special treatment with fillers prior to applying paint coatings. Surface treatment techniques [15] and the ability to correct it through the application of additional coatings [16-18], combined with masking imperfections, would offer an excellent quality tool for reducing the visibility of non-removable structural joints [19,20]. These techniques may also be necessary at a later stage when the need arises for the renovation of vehicle coatings due to wear [21] and corrosion [22-24]. Conversely, the opposite action, avoiding masking, or even anti-masking, which signals presence, is necessary for certain devices or their components that may be hazardous or whose position should be immediately visible. This may occur when, among other factors, applied special coatings such as electrospark deposition [25-27] or diamond-like carbon coatings [28-30] cause the part to visually blend with the surroundings. The evaluation of camouflage or, conversely, anti-masking, largely relies on subjective assessments based on the observations of an observer panel, often using Likert scales. The multidimensionality of visual masking techniques becomes easier to analyze when the dimensionality of the issue is initially reduced, for example, using one of the linear discrimination methods [31,32]. In subsequent steps, one can proceed based on established design of experiments (DOE) methodologies [33-35], and in specific cases, utilizing nonparametric approaches [36-38].

References

[1] M. Laprus (ed.). Leksykon wiedzy wojskowej, MON, Warszawa, 1979.

[2] Maskowanie wojsk i wojskowej infrastruktury obronnej, DD/3.20, MON/SG WP, Warszawa 2010.

[3] R. Bogacki. Maskowanie kolorem. Mat. III Konf. Naukowo Technicznej, WITI 1997, vol.1, p.108.

[4] Instrukcja o maskowaniu wojsk. Sztab generalny WP, MON, Warszawa, 1977.

[5] Norma Obronna NO-80-A200, Farby specjalne do malowania maskującego. Wymagania i metody badań, MON, Warszawa, 2014.

[6] W. Przybył, I. Plebankiewicz, A. Januszko, C. Śliwiński, W. Malej. Zobrazowania środowiska oraz modele obiektów wojskowych w wirtualnej metodzie oceny skuteczności maskowania, in: Wybrana problematyka w technologiach inżynierii mechanicznej, (2020), Politechnika Świętokrzyska, Kielce, 234-242.

[7] C. Murphy, B. Fraster, F. Bunting. Real World Color Management, 2nd Edition, Peachpit Press Publications, 2004. ISBN 978-0321267221

[8] Canon Inc. Technical datasheet for Canon EOS 50D Mark III.

[9] P. Francuz. Imagia, w kierunku neurokognitywnej teorii obrazu, Wyd. KUL, Lublin, 2013. ISBN 978-83-7702-706-6

[10] NATO RTO, Guidelines for Camouflage Assessment Using Observers (RTO-AG-SCI-095), NATO RTO, 2006.

[11] R. Ulewicz. Outsorcing quality control in the automotive industry, MATEC Web of Conf. 183 (2018) art.03001. https://doi.org/10.1051/matecconf/201818303001

[12] R. Ulewicz, F. Nový. Quality management systems in special processes, Transp. Res. Procedia 40 (2019) 113-118. https://doi.org/10.1016/j.trpro.2019.07.019

[13] A. Pacana et al. Analysis of quality control efficiency in the automotive industry, Transp. Res. Procedia 55 (2021) 691-698. https://doi.org/10.1016/j.trpro.2021.07.037

[14] N. Radek, R. Dwornicka. Fire properties of intumescent coating systems for the rolling stock, Commun. - Sci. Lett. Univ. Zilina 22 (2020) 90-96. https://doi.org/10.26552/com.C.2020.4.90-96

[15] N. Radek et al. The influence of plasma cutting parameters on the geometric structure of cut surfaces, Mater. Res. Proc. 17 (2020) 132-137. https://doi.org/10.21741/9781644901038-20

[16] N. Radek et al. Technology and application of anti-graffiti coating systems for rolling stock, METAL 2019 28th Int. Conf. Metall. Mater. (2019) 1127-1132. ISBN 978-8087294925

[17] N. Radek et al. The effect of laser beam processing on the properties of WC-Co coatings deposited on steel. Materials 14 (2021) art. 538. https://doi.org/10.3390/ma14030538

[18] N. Radek et al. Formation of coatings with technologies using concentrated energy stream, Prod. Eng. Arch. 28 (2022) 117-122. https://doi.org/10.30657/pea.2022.28.13

[19] N. Radek et al. The impact of laser welding parameters on the mechanical properties of the weld, AIP Conf. Proc. 2017 (2018) art.20025. https://doi.org/10.1063/1.5056288

[20] N. Radek et al. Properties of Steel Welded with CO2 Laser, Lecture Notes in Mechanical Engineering (2020) 571-580. https://doi.org/10.1007/978-3-030-33146-7_65

[21] S. Marković et al. Exploitation characteristics of teeth flanks of gears regenerated by three hard-facing procedures, Materials 14 (20210 art. 4203. https://doi.org/10.3390/ma14154203

[22] M. Scendo et al. Purine as an effective corrosion inhibitor for stainless steel in chloride acid solutions, Corr. Rev. 30 (2012) 33-45. https://doi.org/10.1515/CORRREV-2011-0039

[23] T. Lipinski, J. Pietraszek. Influence of animal slurry on carbon C35 steel with different microstructure at room temperature, Engineering for Rural Development 21 (2022) 344-350. https://doi.org/10.22616/ERDev.2022.21.TF115

[24] T. Lipiński, J. Pietraszek. Corrosion of the S235JR Carbon Steel after Normalizing and Overheating Annealing in 2.5% Sulphuric Acid at Room Temperature, Mater. Res. Proc. 24 (2022) 102-108.

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

[26] N. Radek, J. Pietraszek, A. Gadek-Moszczak, Ł.J. Orman, A. Szczotok. The morphology and mechanical properties of ESD coatings before and after laser beam machining, Materials 13 (2020) art. 2331. https://doi.org/10.3390/ma13102331

[27] N. Radek et al. The effect of laser treatment on operational properties of ESD coatings, METAL 2021 30th Ann. Int. Conf. Metall. Mater. (2021) 876-882. https://doi.org/10.37904/metal.2021.4212

[28] N. Radek et al. Microstructure and tribological properties of DLC coatings, Mater. Res. Proc. 17 (2020) 171-176. https://doi.org/10.21741/9781644901038-26

[29] N. Radek et al. Influence of laser texturing on tribological properties of DLC coatings, Prod. Eng. Arch. 27 (2021) 119-123. https://doi.org/10.30657/pea.2021.27.15

[30] N. Radek et al. Operational properties of DLC coatings and their potential application, METAL 2022 – 31st Int. Conf. Metall. Mater. (2022) 531-536. https://doi.org/10.37904/metal.2022.4491

[31] J. Pietraszek et al. The principal component analysis of tribological tests of surface layers modified with IF-WS2 nanoparticles, Solid State Phenom. 235 (2015) 9-15. https://doi.org/10.4028/www.scientific.net/SSP.235.9

[32] J. Pietraszek, E. Skrzypczak-Pietraszek. The uncertainty and robustness of the principal component analysis as a tool for the dimensionality reduction. Solid State Phenom. 235 (2015) 1-8. https://doi.org/10.4028/www.scientific.net/SSP.235.1

[33] J. Pietraszek, A. Szczotok, N. Radek. The fixed-effects analysis of the relation between SDAS and carbides for the airfoil blade traces. Archives of Metallurgy and Materials 62 (2017) 235-239. https://doi.org/10.1515/amm-2017-0035

[34] R. Dwornicka, J. Pietraszek. The outline of the expert system for the design of experiment, Prod. Eng. Arch. 20 (2018) 43-48. https://doi.org/10.30657/pea.2018.20.09

[35] J. Pietraszek, N. Radek, A.V. Goroshko. Challenges for the DOE methodology related to the introduction of Industry 4.0. Prod. Eng. Arch. 26 (2020) 190-194. https://doi.org/10.30657/pea.2020.26.33

[36] J. Pietraszek. The modified sequential-binary approach for fuzzy operations on correlated assessments, LNAI 7894 (2013) 353-364. https://doi.org/10.1007/978-3-642-38658-9_32

[37] J. Pietraszek et al. Non-parametric assessment of the uncertainty in the analysis of the airfoil blade traces, METAL 2017 26th Int. Conf. Metall. Mater. (2017) 1412-1418. ISBN 978-8087294796

[38] J. Pietraszek et al. The non-parametric approach to the quantification of the uncertainty in the design of experiments modelling, UNCECOMP 2017 Proc. 2nd Int. Conf. Uncert. Quant. Comput. Sci. Eng. (2017) 598-604. https://doi.org/10.7712/120217.5395.17225