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MAŠĪNBŪVES TEHNOLOĢIJA UN SILTUMTEHNIKA

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ABSTRACT BOOK
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SATURS

MECHANICAL ENGINEERING TECHNOLOGY AND HEAT ENGINEERING

DAŽĀDU SILTUMIZOLĀCIJAS RISINĀJUMU ANALĪZE SILTUMA AKUMULATORAM

ANALYSIS OF DIFFERENT THERMAL INSULATION SOLUTIONS OF A HEAT STORAGE

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Galvenais šī darba mērķis ir noteikt trīs reālu siltuma akumulatoru siltumizolācijas risinājuma efektivitāti un veikt to analīzi. Pētījumā tika modulēti trīs dažādi siltumizolācijas risinājumi uz siltuma akumulatoru ar tilpumu $V = 5000\ \mathrm{m}^3$. Siltumizolācijas viens no svarīgākajiem parametriem ir tās biezums un λ jeb atsevišķu slāņu materiālu siltumvadītspējas koeficienti W/m·K [1], kas kopā veido siltuma caurlaidības koeficientu *U*. Siltuma caurlaidības koeficients *U* ir atkarīgs no katra materiālu termiskās pretestības un biezuma [4]:

$$U = 1/R \quad [\mathrm{W/(m^2 \cdot K)}], \tag{1}$$

$$\text{kur } R = R_1 + R_2 + R_n = \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_n}{\lambda_n} \tag{2}$$

1. tabula. Siltuma akumulatoru izolācijas risinājumi [2, 3]

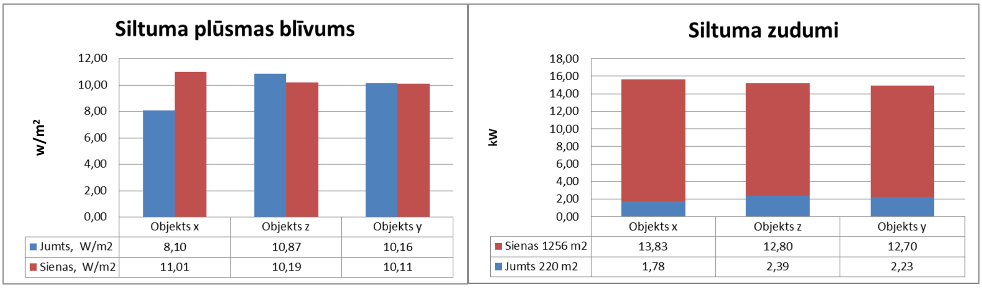
Konstrukcijas nosaukums	Slānis	Objekts, materiāls	Biezums, m	λ, W(m·K)	Objekts, materiāls	Biezums, m	λ, W(m·K)	Objekts, materiāls	Biezums, m	λ, W(m·K)
		Objekts x			Objekts z			Objekts y		
Rezervuāra jumts	1	Tērauds	0,006	50	Tērauds	0,006	50	Tērauds S355 J2H	0,006	50
	2	Krāsa (poluritāna bāze)	0,0002	0,2	Krāsa (poluritāna bāze)	0,0002	0,2	Krāsa (poluritāna bāze)	0,0002	0,2
	3	Rokwool sl960	0,5	0,045	PAROC ROS 30	0,26	0,036	PAROC ROS 30	0,3	0,036
	4	Apšuvuma skārds	0,0006	14,4	PAROC ROS 50	0,04	0,038	PAROC ROB80	0,02	0,038
	5				Apšuvuma skārds	0,0006	14,4	Apšuvuma skārds	0,0006	14,4
			U, $W/m^2 \cdot K$	**0,090**			**0,121**			**0,113**
Rezervuāra sienas	1	Tērauds	0,18	50	Tērauds	0,012	50	Tērauds S355 J2H	0,08	50
	2	Krāsa (poluritāna bāze)	0,002	0,2	Krāsa (poluritāna bāze)	0,002	0,2	Krāsa (poluritāna bāze)	0,002	0,2
	3	Rokwool sl930	0,4	0,049	PAROC WAS 50	0,3	0,034	PAROC ROS 30	0,3	0,036
	4	Apšuvuma skārds	0,0006	14,4	Apšuvuma skārds	0,0006	14,4	PAROC WAB 10t	0,02	0,036
	5							Apšuvuma skārds	0,0006	14,4
			U, $W/m^2 \cdot K$	**0,122**			**0,113**			**0,112**

Veikts aprēķins siltuma pārejai stacionārā režīmā akumulatoram ar ģeometriskiem izmēriem 220 m^2 jumtam un 1246 m^2 sienām gaisa temperatūrā 0 °C un ūdens temperatūras rezervuāra iekšienē 90 °C . Siltuma plūsmas blīvumu aprēķina pēc formulas: [1]:

$$\Phi = \frac{t_{v1} - t_{v2}}{\sum_{i=1}^{n} \frac{\delta_i}{\lambda_i}} \qquad (W/m^2).$$

Siltuma zudumi visam siltuma akumulatora laukumam (jumts, sienas) [1]:

$$\Phi' = \frac{t_{v1} - t_{v2}}{\sum_{i=1}^{n} \frac{\delta_i}{\lambda_i}} \, S \qquad (W).$$



Siltuma plūsmas blīvums W/m^2 pa kreisi un siltuma zudumi visā rezervuāra laukumā (jumts, sienas).

Veicot aprēķinus un datu analīzi, redzams (1. att.), ka jumtam visefektīvākais ir objekta x risinājums, kur siltuma plūsma veido 8,1 W/m^2, savukārt sienām šim objektam ir vislielākā siltuma plūsma – 11,01 W/m^2. Sienām vismazākā siltuma plūsma ir objektam y – 10,11 W/m^2. Siltuma plūsma tieši korelē ar *U* vērtību. Lai varētu novērtēt siltumizolācijas risinājumu kopumā, tika aprēķināti zudumi caur visu ārējo virsmu laukumu akumulatoram, kur objekta y risinājumam ir vismazākie kopējie siltuma zudumi – 14,93 kW. Objektam z tie bija par 1,7 % lielāki, savukārt objektam x – par 4,5 % lielāki.

Secinājumi

1. Trīs dažādie siltumizolācijas risinājumi, kas atšķiras gan ar biezumu, gan ar siltumizolācijas materiālu izvēli, parāda, ka vislabākā U vērtība jumtam ir objektam x – 0,0899 W/(m^2·K). Šajā objektā jumtam izmantots *Rockwool sl960* siltumizolācijas materiāls piecās kārtās 0,5 m biezumā. Sienām visefektīvākais risinājums ir objektam y – 0,0112 W/(m^2·K), kur siltumizolācijas materiāls klāts četrās kārtās 0,320 m biezumā.
2. Veicot aprēķinu stacionāram režīmam trīs dažādu sienu siltumizolācijas risinājumiem rezervuāram ar ģeometriskiem izmēriem – 1256 m^2, jumtam – 220 m^2, gaisa temperatūra – 0 °C un akumulatora ūdens temperatūra – 90 °C, tika secināts, ka visefektīvākais ir objekta y kopējais (sienas un jumta) risinājums, kuram ir vismazākie kopējie siltuma zudumi – 14,93 kW. Objektam z tie bija par 1,7 % lielāki, savukārt objektam x – par 4,5 % lielāki.

Informācijas avoti

1. Nagla J., Saveļevs, P., Ciemiņš, R. Siltumtehnikas pamati, Rīga "ZVAIGZNE" 1981.
2. Paroc, SIA interneta vietne, pieejams: https://www.paroc.lv/izstradajumi/konstrukcijas.
3. Rockwool Group interneta vietne: https://www.rockwool.com/group/.
4. Ministru kabineta noteikumi Nr. 280 Rīgā 2019. gada 25. jūnijā (prot. Nr. 30 1. §) Noteikumi par Latvijas būvnormatīvu LBN 002-19 "Ēku norobežojošo konstrukciju siltumtehnika".

SILTUMA AKUMULATORA EFEKTIVITĀTES PALIELINĀŠANA, IZMANTOJOT ABSORBCIJAS SILTUMSŪKNI

INCREASING THE EFFICIENCY OF THE HEAT STORAGE BY USING AN ABSORPTION HEAT PUMP

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Latvijas kurss uz klimatnetralitāti ir saistīts ar siltumsūkņu un enerģijas akumulāciju vēl plašāku izmantošanu. Ir labi piemēri siltumsūkņu un siltuma akumulācijas iekārtu izmantošanai, taču abu iekārtu apvienošana sniegtu vēl lielāku stacijas kopējas efektivitātes paaugstināšanu [2].

Viens no būtiskākajiem siltumenerģijas akumulatoru kritērijiem ir akumulētās enerģijas daudzums. Siltumietilpības akumulatoriem ar mainīgu temperatūru, kur par darba vielu izmanto siltumtīklu ūdeni, temperatūras starpība un tilpums tiešā veidā ietekmē tā siltumietilpību.

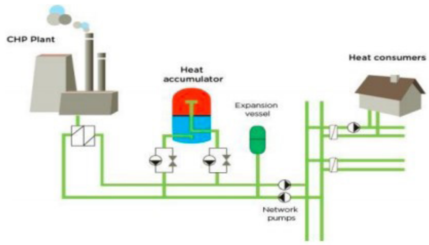
Siltumietilpību aprēķina pēc formulas [4]:

$$Q = V\rho\, c_p (T_1 - T_2)\ [\mathrm{J}], \tag{1.1}$$

kur:

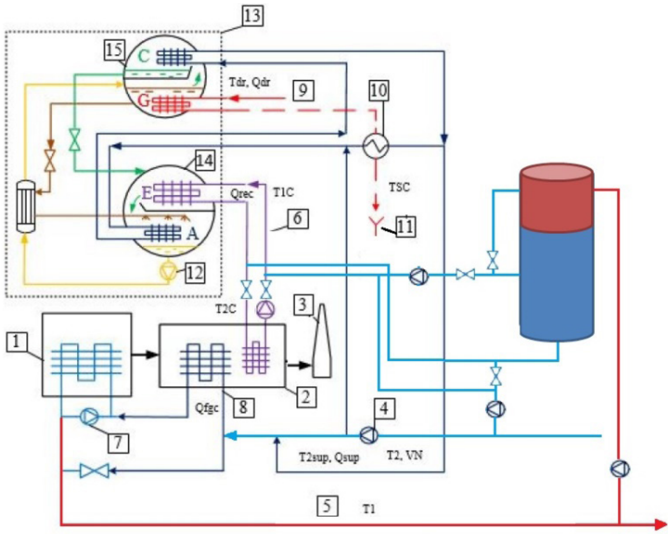
- Q – siltuma daudzums (J);
- V – vielas tilpums (m^3);
- ρ – vielas blīvums (kg/m^3);
- c_p – ūdens īpatnējā siltumietilpība (J/kg ·°C);
- T_1 un T_2 – temperatūras karstai un augstai zonai (°C).

Siltuma akumulatora siltumietilpība ir tieši saistīta ar siltumtīklu grafiku. Klasiska akumulatora slēguma shēma redzama 1. attēlā.



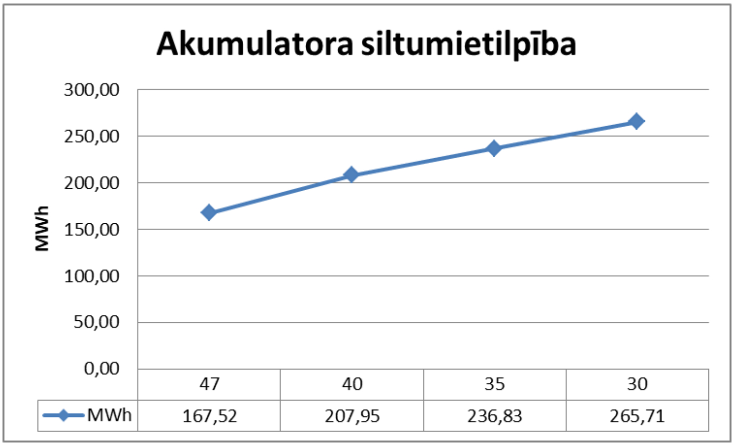
1. att. Siltuma akumulatoru vienkāršota pieslēguma shēma [5].

Kombinācijas gadījumā, kad tiek izmantots siltumsūknis un siltuma akumulators, lai panāktu maksimālu efektu (2. att.), siltumsūknis galvenokārt tiek izmantots, lai noņemtu siltumu no dūmgāzēm, bet, izmainot slēguma shēmu, ir iespēja uzlabot siltuma akumulatora darbības parametrus. Izveidotajā slēguma shēmā parādīts, ka ar siltumsūkni tiek dzesēts atgaitas ūdens, kas nonāk siltuma akumulatorā. Pie daļēji izlādēta vai pilnīgi izlādēta akumulatora var veikt temperatūras pazemināšanu ar recirkulācijas palīdzību, kad izlādes process ir pārtraukts.



2. att. Absorbcijas tipa siltumsūkņa darbības shēma ar siltuma akumulatoru [1].

Modulējot akumulatora siltumietilpību ar tilpumu 5000 m^3 gaisa temperatūrā 0 °C, pēc Rīgas pilsētas siltumtīkla temperatūras grafika, kur tīklu turpgaitas temperatūra ir 76 °C, tīklu atgaitas – 47 °C [3], akumulatora ietilpība ir 167,52 MWh. Veicot režīmu izpēti un modulēšanu, kur akumulatora izlādes procesā tiek dzesēts akumulatora ieplūstošais (tīklu atgaitas) ūdens (3. att.), var redzēt, ka, samazinot temperatūru no 47 °C līdz 30 °C, tika panākta par 58 % lielāka siltumietilpība.



3. att. Siltuma akumulatora ietilpības atkarība no atpakaļgaitas temperatūras.

Secinājumi

1. Veicot pētījumu par akumulatora izlādes procesu, kurā akumulatorā uzpildāmā atgaitas ūdens temperatūra tiek pazemināta un veikta aukstā ūdens dzesēšana ar recirkulāciju, var panākt 58 % lielāku akumulatora siltumietilpību, pazeminot temperatūru no 47 °C uz 30 °C.
2. Stacijās, kur plānots paaugstināt efektivitāti, veicot akumulācijas iekārtas un siltumsūkni izbūvi, iespējams būvēt mazāka tilpuma siltuma akumulācijas tverni, ieekonomējot izmaksas.

Informācijas avoti

1. Rusovs, D., Žentiņš, V. Steam Driven Absorption Heat Pump and Flue Gas Condenser Applied for Heat Recovery in District Heating Network. No: 19th International Scientific Conference "Engineering for Rural Development": Proceedings. Vol. 19, Latvija, Jelgava, 20.–22. maijs, 2020. Jelgava: Latvia University of Life Sciences and Technologies, 2020, 1627.–1632. lpp. ISSN 1691-5976. Pieejams: doi:10.22616/ERDev.2020.19.TF418.
2. Rusovs, D., Jaundālders, S., Stanka, P. Pumped Thermal Electricity Storage Integration in District Heating Systems. No: 2020 IEEE 61st International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON 2020): Conference Proceedings, Latvija, Riga, 5.–6. novembris, 2020. Piscataway: IEEE, 2020, 9.–12. lpp. ISBN 978-1-7281-9511-7. e-ISBN 978-1-7281-9510-0. Pieejams: doi:10.1109/RTUCON51174.2020.9316560.
3. AS "RĪGAS SILTUMS" siltumtīklu grafiks.
4. Nagla J., Saveļevs, P., Ciemiņš, R. Siltumtehnikas pamati, Rīga "ZVAIGZNE" 1981.
5. Dyrelund, A. Presentation on 4th Generation of Energy Supply Systems: "The Back Bone of Liveable and Resilient Campuses and cities", 06.12.2017. Pieejams: https://www.districtenergy.org/viewdocument/4th-generation-of-energy-supply-sys.

INFLUENCE OF ACTUAL FOOD RETAIL AND REFRIGERATION SITUATION ON THE GREEN DEAL INDICATORS: 2021 REVIEW OF THE LATVIAN MARKET

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The sustainable development and the Green Deal targets [1] for refrigeration include a reduction of direct greenhouse gas emissions towards decarbonisation through the transition of systems and equipment to low global warming potential (GWP) refrigerants, with a stronger focus on the use of natural refrigerants, as well as the decentralization of commercial equipment. Sustainable refrigeration means increasing of energy efficiency of equipment and systems, which is provided by new EC ecodesign [2] and energy labelling [3] regulation requirements, which came into force on March 1, 2021.

As a part of applied comprehensive research in 2021, in addition to Latvian food retail market segmented analysis, the visual technical investigation of 10 operating convenience food stores was performed by collecting the available data. The main focus was on the types and technical condition of display cases and used refrigerants, as well as other technical information. Further evaluation and data analysis based on mathematical, grapho-analytical, etc. methods were carried out.

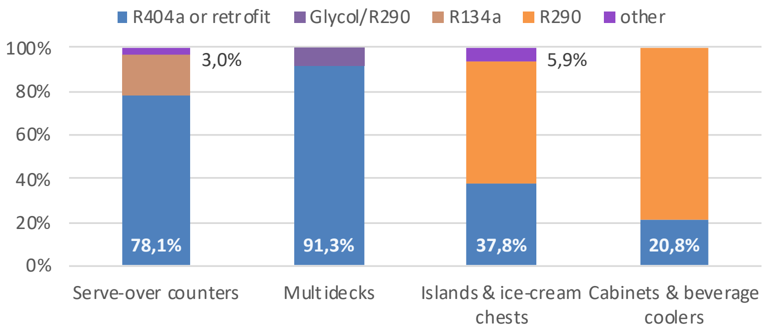

Figure 1. The specific weight of refrigeration display cases (length in meters) by type and refrigerant: data of 10 convenience stores of 5 food retail chains in Latvia (2021).

As it is shown in Figure 1, one of the most crucial criteria of carbon neutrality targets and sustainable refrigeration development in food retail is the refrigerant used in the system. During the last decade in Latvia the modernization has been going on in supermarkets and food stores. This research shows that there is still space for further improvements and optimization and there is still a high proportion of display cases older than 5 years and very high proportion of R404a and other HFC and high GWP level refrigerant blend units (length in meters: 68.4 % – R404a or retrofit and 5 % – R134a, or another HFC of explored 142 refrigeration display case units with the total length of 262.7 m).

Results of the study show that it is important to involve national government in futher research of Latvian refrigeration market with special attention to the statistical and technical data of the industry and its collection and monitoring, as well to the development of urgent action plans for reaching the Green Deal goals.

References

1. European Commission, *EU climate action and the European Green Deal*. https://ec.europa.eu/clima/policies/eu-climate-action_en.
2. Commission Regulation (EU) 2019/2024 laying down ecodesign requirements for refrigerating appliances with a direct sales function pursuant to Directive 2009/125/EC of the European Parliament and of the Council (2019). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.315.01.0313.01.ENG.
3. Commission Delegated Regulation (EU) 2019/2018 supplementing Regulation (EU) 2017/1369 of the European Parliament and of the Council with regard to energy labelling of refrigerating appliances with a direct sales function (2019). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R2018.

DEPOSITION OF NANOSTRUCTURED SUPERLATTICE COATINGS BY ADVANCED PVD TECHNIQUE

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The advanced Physical Vapor Deposition (PVD) technique based on a novel High-Power Ion-Plasma Magnetron Sputtering (HiPIPMS) phenomenon was applied for the deposition of nanostructured superlattice coatings (NSC). The HiPIPMS technology was implemented on the thin film modular deposition system (TF-MDS, Figure 1) [1], [2]. TF-MDS was used in the effective crossed field unbalanced magnetron sputtering ion-plasma mode, which provided a highly ionized plasma in the whole sample-substrate region – immersed sputtering plasma mode. The four workstations, having two magnetron sputtering devices (MSD) each of them, were cross-configured on the circumference inside the vacuum chamber that allows very specific combinations of monolithic and mosaic type magnetron sputtering targets (MST) depending on chemical composition of the NSC. Sputter cleaning was performed prior to the film deposition by a collimated linear ion beam device, which was also used for film growing activation and resputtering weakly accommodated particles during the film deposition process.

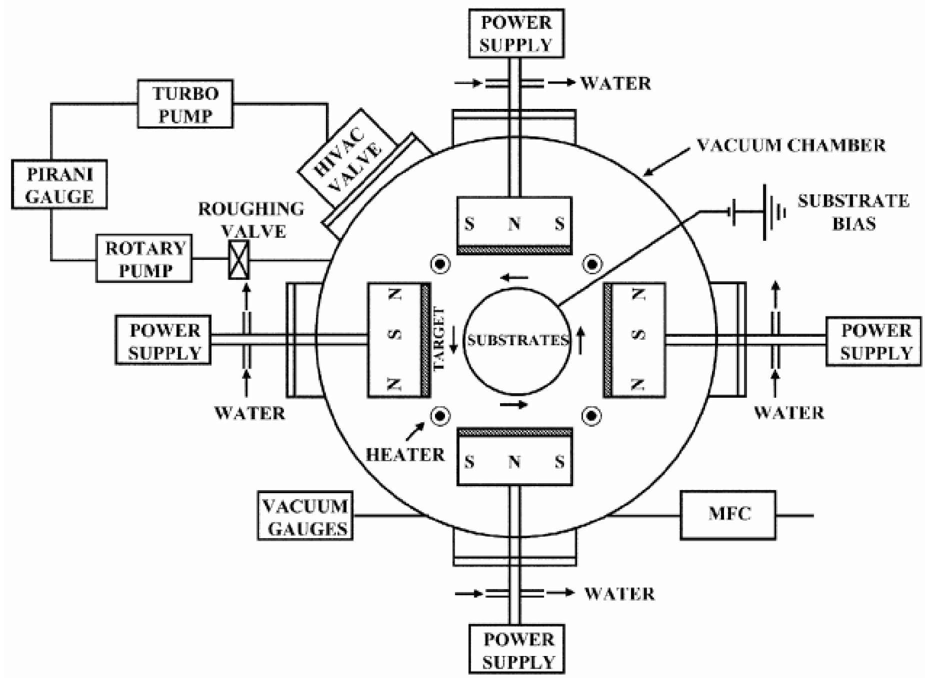

Figure 1. Schematic diagram of the Thin Film Modular Deposition System (TF-MDS) equipped by 4 workstations having two magnetron sputtering devices (MSD), each of them operating in HiPIPMS mode.

The most important parameters of the HiPIPMS-PVD process regarding the NSC film growth were the following: (i) base pressure in vacuum chamber, $p_b = 0.131$ mPa; (ii) total operating gas pressure of the sputtering gas (Ar/N_2), $p_{sg} = 0.36$ Pa; (iii) partial gas flow rate, $p_{sg} = 12.4$ l/h; (iv) substrate heating and *in-situ* sputter cleaning procedure using collimated linear ion beam etching at 1800 V × 140 mA prior to film deposition; (v) distance between MSS and substrate $L = 85$ mm; (vi) substrate temperature during PVD deposition process was kept at 350 °C; (vii) electrical power regime of magnetron sputtering sources was maintained at 640 V × 8.4 A on each workstation so that DC discharge power density exceeded 60 W/cm^2 threshold needed for equal-rate sputtering conditions of the mosaic type sputtering targets [2]; (viii) NSC film deposition rate at 2D rotation was kept at 180 nm/min; (ix) negative bias voltage during deposition process was maintained at 90 V causing the bias current of about 350–500 mA depending on sputter discharge power.

Thus, tribological NSCs were deposited on bearing steel (100Cr6) and Si-wafers by means of the HiPIPMS technology allowing to reach high mechanical and tribological properties of multi-layered coatings. NSCs on the carbonitride basis were produced as thick as 2000–6000 nm, depending on specific application purposes. For instance, wear resistant NSCs with thickness about 2000–3000 nm are good enough for bearings, as for tribochemical and corrosion resistant applications even thicker NSCs are needed. Multilayer coatings composed of 2–3 coherently stacked, alternating materials with a spatial periodicity in the nanometre range, referred to as superlattice coatings, have been reported to possess exceptional high hardness values exceeding that of their single sub layered constituents by 300 hundred and even more percent [3].

Within this work we produced, investigated, and tested novel self-healing multi-functional NSCs with low friction and ultra-high wear resistance for high-tech applications, e. g., as machine components operating as friction partners in highly aggressive environment, as metal cutting and hot forming tools, etc. The above mentioned NSCs were modified non-stoichiometric carbonitride films having compositional elements like TiAlSi-CN:Me/a-C:Si_3N_4 allowing to achieve a novel solution that sufficiently reduces or even eliminates well-known disadvantages of the hard-carbon-based films, i.e., inherent compressive macro-stresses of the pure amorphous carbon, a-C, and/or hydrogenated amorphous carbon, a-C:H, films. Thus, composite coatings noted here by empirical formula nc-TiAlSi-CN:Me/a-C:Si_3N_4 could be considered as a combination of advanced features inherent to the coatings based on amorphous carbon, a-C, on the one hand, and amorphous silicon nitride, Si_3N_4, as the matrix element, on the other hand. Here by “nc” is meant nanocrystallites.

The chemical composition and structural period of the new type of NSC can be described by the above mentioned stoichiometric formula TiAlSi-CN:Me/a-C:Si_3N_4, where Me = Cr, Nb or Hf. Here Ti, Al, Si, C, N, Cr, Mo and W are commonly used symbols for chemical elements. The base component of the proposed composite coatings is “TiAlSi-CN” in the form of carbonitride nanoparticles (CN-NPs), which play the role of fillers in the nano-composite structure of the NSC. In turn, *AlSi* presence in the CN-NPs provides self-healing properties of the NSC due to specific tribochemical reactions preventing thermal denitrification of the NSC when operating above 300 °C. Furthermore, the additional metallic constituents Me = Cr, Nb or Hf function as a strength and toughness agent to harden the CN-NPs and thus to harden and bind the NSC integral structure. The amorphous carbon, a-C, and amorphous silicon nitride, Si_3N_4, components in the formula above, function as a matrix binding element providing tough cemented composite structure of the NSC. The presence of the a-C as matrix element increases the carbon content and hardens the non-stoichiometric CN-coatings, in turn, Si_3N_4 cements and fills eventual pores and nanovoids between the CN-NPs grains.

Acknowledgements

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References

1. J. Maniks, V. Mitin, U. Kanders, V. Kovalenko, P. Nazarovs, M. Baitimirova, R. Meija, R. Zabels, K. Kundzins, D. Erts, Deformation behavior and interfacial sliding in carbon/copper nanocomposite films deposited by high power DC magnetron sputtering, Surf. Coat. Technol. 276 (2015) 279–285.
2. H. C. Barshilia, K. S. Rajam, Bull. Mater. Sci., Vol. 30, No. 6, December 2007, pp. 1–8. © Indian Academy of Sciences.
3. R. Hahn et al., Superlattice effect for enhanced fracture toughness of hard coatings, Scripta Materialia 124 (2016) pp. 67–70, http://dx.doi.org/10.1016/j.scriptamat.2016.06.030.

INVESTIGATION OF NANOSTRUCTURED SUPERLATTICE COATINGS DEPOSITED BY ADVANCED PVD TECHNIQUE USING SEM AND INDENTATION METHODS

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Nanostructured superlattice coatings, when applied on different materials, can noticeably improve the performance of the substrate surface on which it is deposited [1]. Improvements include hardness increase, chemical resistance, thermal resistance, wear resistance, lower friction, etc. In order to test superlattice coating structure and mechanical parameters, advanced measurement techniques are used. In this study, coating layered structure and composition were analysed with scanning electron microscopes *Tescan Lyra3* and *Thermo Scientific Helios 5*. The obtained results showed that superlattice consists of more than 100 individual 30 nm thick layers (Figure 1 b)).

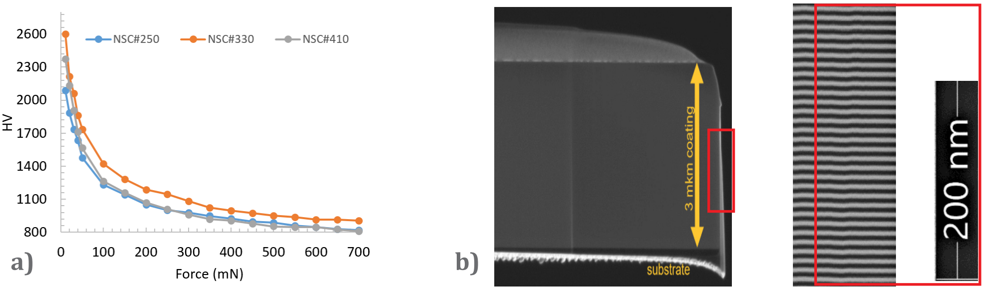

Figure 1. a) – Micro Vickers hardness chart for three different superlattice coating types; b) – example of superlattice coating multilayer structure obtained with SEM.

Using *Mitutoyo HM210D* Micro Vickers testing device superlattice coating microhardness was tested using 18 different testing loads starting from 0.01 N and finishing with 0.7 N. Five measurements were taken per each load to ensure statistically reliable data. Results for three different superlattice coatings are shown in Figure 1a). The graph shows that the applied load increasing rapidly reduces the obtained harness value, and this happens because with higher loads the device fully penetrates through the 3 micrometer coating and already starts to indent softer substrate material. From this graph, one can see that actual coating thickness reaches 2600 HV that exceeds the substrate (100Cr6 steel hardness 800 HV) hardness by up to 3.3 times. Such improvements in hardness result in better surface tribological performance.

Acknowledgements

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References

1. Leitans, A., Lungevics, J., Kanders, U., Boiko, I. Micromechanical and Tribological Properties of Nanostructured Carbonitride Coatings Deposited by PVD Technique. In: Riga Technical University 61st International Scientific Conference “Materials Science and Applied Chemistry 2020” (MSAC 2020): Book of Abstracts, Latvia, Riga, 23–23 October 2020. Riga: Riga Technical University, 2020, p. 59. ISBN 978-9934-22-530-7.

TRIBOLOGICAL PROPERTIES OF NANOSTRUCTURED SUPERLATTICE COATINGS DEPOSITED BY ADVANCED PVD TECHNIQUE

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The present tribological tests were performed using the ball-on-disc tribometer CSM Instruments, where the disk is represented with the sample substrate with the coating, which is rotating, but the ball is a stationary tribometer element. This method complies with ASTM G99 tribology test standard. The coefficient of friction was measured in ambient air, dry friction conditions with 100Cr6, Zr_2O, Si_3N_4, Al_2O_3 balls (Ø=6 mm) under a 1 N load at velocity v = 0.15 m/s for a sliding distance up to 100 m (1000 cycles).

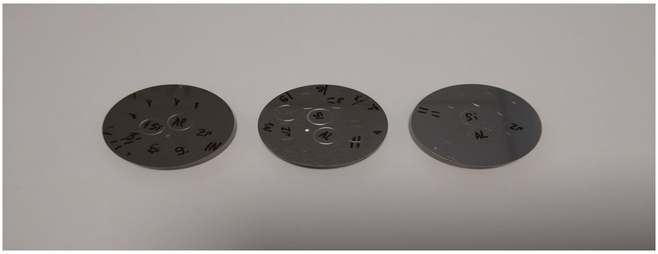

Figure 1. Samples with PVD coating.

A total of 12 tribometer measurements were performed with three coatings and a four-ball at the above experimental settings. All the results of the friction coefficient measurements are summarized in Table 1.

As can be seen, the tribological measurements showed that the lowest friction coefficient values (~0.18) were observed for coating TiAlSiZr) N / (CWC) N, where the friction pair consists of a ball from steel (100Cr6) or Zirconia oxide (ZrO_2).

Table 1. Tribological parameters of the deposited composite coatings

		Ball material		
Coating	100Cr6	Al_2O_3	Si_3N_4	ZrO_2
1202 (TiAlSiZr)N/(CWC)N	0.181	0.327	0.372	0.186
1203(TiAlSiCrNb)N/(TiC)N	0.232	0.431	0.715	0.345
1204 CrN/(SiC)N	0.925	0.854	0.87	0.587

Acknowledgements

This research is funded by the Latvian Council of Science, project No. 2019/1-0385 “Carbon-rich self-healing multifunctional nanostructured smart coatings (NSC) for high-tech applications using high-power confined plasma technology for their deposition”.

References

1. Kanders, U., Lungevičs, J., Leitāns, A., Boiko, I., Bērziņš, K., Trubiņa, Z. Nanostructured TiAlSi-CN:Me/a-CN:Si3N4 Composite Coatings Deposited by Advanced PVD Technique. Solid State Phenomena, 2021, Vol. 320, pp. 37–42. ISSN 1012-0394. e-ISSN 1662-9779. Available from: doi:10.4028/www.scientific.net/SSP.320.37.
2. Leitans, A., Lungevičs, J., Kanders, U., Boiko, I. Micromechanical and Tribological Properties of Nanostructured Carbonitride Coatings Deposited by PVD Technique, Key Engineering Materials, ISSN: 1662-9795, Vol. 903, pp. 177–182, Trans Tech Publications Ltd.

METHODOLOGY FOR MEASURING AND EVALUATION OF COATING CHARACTERISTICS

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Currently, there are more than 30 standardized surface texture characteristics, thereby it is important to choose the most appropriate one to characterize a particular surface. Only a few studies have investigated the correlation between surface texture and friction-wear characteristics [1]. In [2] it was concluded that 3D-texture analysis can be efficiently applied for solving practical tribological problems at the micro/nanoscale level. It was pointed out [3] that the basic amplitude parameters that are commonly used to describe surface texture are not enough for determining the tribological properties of contact surfaces. Therefore, other surface texture parameters should be used to describe the tribological properties of the friction pairs.

Another issue is texture filtration in surface roughness measurements [4]. Standardized roughness measurements (ISO 4287 and ISO 25178) require filtration of the geometrical form and waviness of the measured surface topography, thus the values of the 3D-texture parameters change as well. In tribological tests the actual surface (not filtered) is in contact, therefore, the primary surface should be analysed as well.

The obtained nano-coating surface texture characteristics will be analysed in relation to tribological measurements. Methodology for measuring and evaluating the characteristic of wear-resistant nanostructured coatings will be developed.

Three different nanocoatings were applied to a 100Cr6 substrate (see Figure 1), and the surface roughness value *Sa* (arithmetical mean height) of surface characteristics was obtained using a standardized surface roughness measurement methodology, as well as *Sa* was calculated from the primary surface (see Table 1).

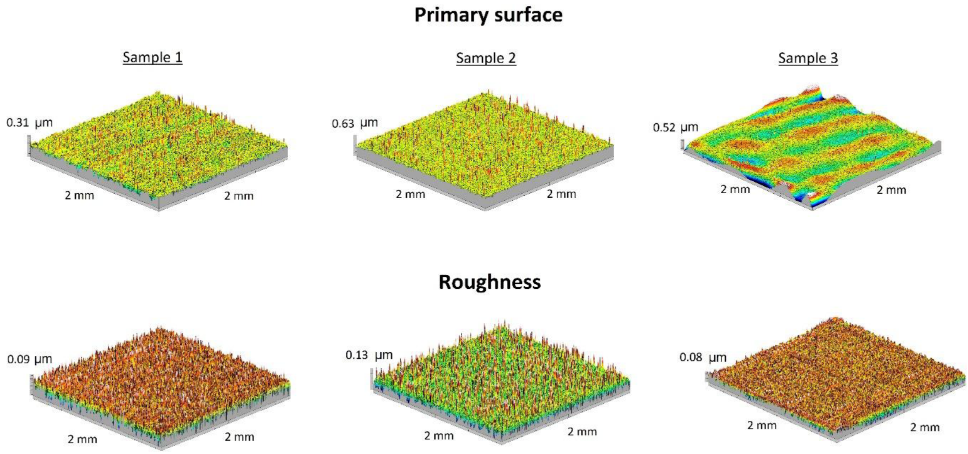

Figure 1. Surface textures: Sample 1 – (TiAlSiZr)N/(CWC)N;
Sample 2 – (TiAlSiCrNb)N/TiC(N); Sample 3 – CrN/(SiC)N.

It can be seen in Figure 1 that the surfaces of the 3 samples are visually different, especially of Sample 3, but when the form and waviness are filtered, the surface differences in terms of roughness are negligible. Table 1 shows the numerical values of parameter *Sa*. In the case of the primary surface, the value of *Sa* is significantly higher for Sample 3, but if only the roughness is considered, then the values of *Sa* do not differ significantly.

Table 1. *Sa* values calculated from the primary surface and from filtered roughness

	Sa value (nm)	
	Primary surface	Filtered Roughness
Sample 1	16.8	11.2
Sample 2	17.3	11.7
Sample 3	54	11

Looking at only one surface texture parameter *Sa*, significantly different values were observed using two different roughness measurement methods. The next step will be to analyse the other 3D standardized parameters and primarily select the parameters that can be used to characterize nanocoatings. The selected parameters will then be compared with tribological measurements (wear and friction co-efficient), thus analysing the correlation. Taking into account the correlation data and excluding multicollinearity, the amount of 3D parameters used will be significantly reduced. From the obtained data, a measurement methodology will be developed based on standards ISO 5725, GOST R 8.563.

Acknowledgements

This research is funded by the Latvian Council of Science, project No. 2019/1-0385 "Carbon-rich self-healing multifunctional nanostructured smart coatings (NSC) for high-tech applications using high-power confined plasma technology for their deposition".

References

1. Quanren Zeng et al., Correlating and evaluating the functionality-related properties with surface texture parameters and specific characteristics of machine components, International Journal of Mechanical Sciences 149 (2018), pp. 62–72.
2. N. K. Myshkina & A. Ya. Grigorieva, Roughness and texture concepts in tribology, Tribology in Industry, 35(2), 2013, 97–103.
3. A. Dzierwa, Effects of surface preparation on friction and wear in dry sliding conditions, Tribologia, No 2, 2017, 25–31.
4. J. Lungevics, E. Jansons, I. Boiko, I. Velkavrh, J. Voyer, T. Wright, A Holistic Approach Towards Surface Topography Analyses for Ice Tribology Applications, Front. Mech. Eng. 7 (2021) 56. https://doi.org/10.3389/FMECH.2021.691485.

INFLUENCE OF ADDITIVE MANUFACTURING PROCESS PARAMETERS ON TITANIUM GRADE 5 MECHANICAL PROPERTIES

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In this study the influence of processing parameters of additive manufacturing on material density and mechanical properties was performed. Material for this study was Ti6-Al-4V [1] and parts produced by additive manufacturing (AM) by means of metal laser sintering, especially by a fibre laser 3D printer. The influence of technological parameters such as layer thickness, hatch spacing, laser travel speed, and laser power were analysed. Based on the energy of those parameters, density was calculated to observe necessary energy level for this material [2]. The first part of the study was devoted to material density research. Many processing parameter combinations were examined to find parameters which can maintain material density higher than 97 %.

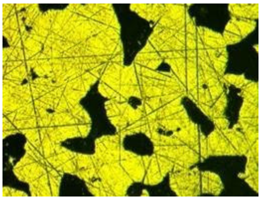
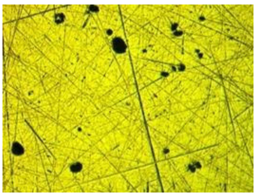
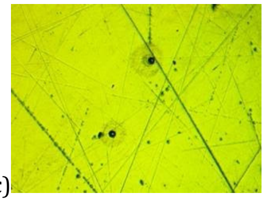
a)  b)  c) 

Figure 1. a) Microstructure of a sample with a density of 79 %;
b) – microstructure of a sample with a density of 98 %; and
c) microstructure of sample with a density of 99.8 % enlarged by 50x.

The second part of the study was devoted to investigating how additive manufacturing process parameters influence the mechanical properties of Ti6-Al-4V. The research indicates that optimal energy density for this material was in the range between 80 and 130 J/mm^3. The best results were reached with the following parameters: layer thickness 0.07 mm; hatch spacing 0.1 mm; laser travel speed 80 mm/s; and laser power 80 W. Samples that were produced with those parameters could reach tensile strength of more than 1000 MPa and elongation above 7 %.

References

1. M. J. Donachie, Titanium: A Technical Guide, second ed. ASM International, Materials Park, OH, 2000.
2. Shunyu Liu, Yung C. Shin. Additive manufacturing of Ti6Al4V alloy: A review. Shunyu Liu, Yung C. Shin. Center for Laser-based Manufacturing, School of Mechanical Engineering, Purdue University, West Lafayette, IN 47906, USA. Materials and Design 164 (2019) 107552, 1–23.

MACHINING OF TITANIUM ALLOYTi6AL4V MADE BY ADDITIVE MANUFACTURING

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Machining of Titanium alloy Ti6Al4V made by additive manufacturing is an emerging future. There are a lot of studies on Ti6AL4V 3D printed samples [1]–[4], but there is none on the influence of machining post printing. In additive manufacturing of Ti6Al4V alloy, it is necessary to perform a finishing operation to improve the surface quality and to ensure precise geometry tolerances. During this process, the workpiece properties may be affected, such as micro hardness, microstructure, internal defect distribution, internal stresses. The very high temperatures involved in the MPBF (Metal Powder Bed Fusion) process can cause significant stresses to build up in parts as they build. These stresses can result in delamination of the layers, cracks in the part, distortion, and warpage during post finishing. During printing there are lots of stresses created, heat treatment is done to normalize the parts. Machining (using milling machine) also causes internal stresses, which can damage the surface and the part itself. Optimisation of machining parameters and printing parameters can solve this issue.

Here we give an overview of effective machining parameters, effect of machining on internal stress and defect distribution in the part. The defect distribution and internal stress distribution is studied by using CT equipment. A solution is presented to improve the mechanical properties of 3D printed Ti6Al4V alloy.

Acknowledgements

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References

1. Sayed Ali, Niknam; Riad, Khettabi; Victor, Songmene; Machinability and Machining of Titanium Alloys; A Review. In book: Machining of Titanium alloys, Chapter 1, Publisher: Springer-Verlag Berlin Heidelberg 2014, Editors: J. P. Davim. https://researchgate.net/publication/280233219.
2. Md, Manjurul, Ahsan; 3D Printing and Titanium alloys: A paper review by Md Manjurul Ahsan, 2016. https://researchgate.net/publication/319713132.
3. Shunyu, Liu; Yung C. Shin; Additive manufacturing of Ti6Al4V alloy: A review. 2018, https://www.sciencedirect.com/science/article/pii/S026412751830916X.
4. Karolina, Karolewska; Bogdan, Ligaj; Comparison analysis of titanium alloy Ti6Al4V produced by mettalurgical and 3D printing method; 2019, AIP conference Proceedings 2077(1):020025. https://researchgate.net/publication/331283009.

DEVELOPMENT OF POLYMER BLENDS FOR 3D PRINTING APPLICATION

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3D printing is a fast-growing manufacturing technology in the modern engineering because of customised production, recyclability and the possibility to produce complex components. Printing material used for this process plays an important role, which can affect the final properties of printed products. In this project, we are mainly interested in several factors while developing the printing polymer blends. The main thing is that these blends are purely biodegradable and eco-friendly. Most of the content used in these blends is natural and plant-based (PLA).

Based on the previous experimental results and evaluation of the PLA/PBAT polymer blend 3D printing we have observed several possibilities and the future scope of these blends in production engineering applications [1]. The PLA/PBAT blends are biodegradable and have better mechanical properties in a specific level of combination. The addition of thermoplastics starch (TPS) in these blends can improve overall properties.

Plant-based starch is easily available in nature, and after a few low-cost processes these can be converted to thermoplastics. For instance, Cassava Starch is easily available in nature at low cost. Several studies mention the benefits and properties of these thermoplastic starch and blends.

Combination of thermoplastic starch (TPS) in the PLA/PBAT blend and the result gained from this can be limited, but the addition of natural fibres can improve the bonding between layers and also increase the properties such as mechanical and thermal stability of polymer 3D printed samples. These additions of natural fibres increase the crystallinity in polymers, therefore high stiffness and strength can be gained. Several research papers mention that these changes depend on the percentage of composition of TPS and Cassava fibre. The increase of percentage of fibre can affect oppositely these properties.

Here the developed natural PLA and TPS are used for 3D printing and the properties are evaluated by conducting several tests. The addition of several natural powdered fibres into these blends and changes in properties also are studied.

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References

1. Eliangela de M. Teixeira; Antonio A. S. Curvelo; Anna C. Correa; Jose M. Marcocini; Gregory M. Glenn; Luiz H. C. Mattoso, Properties of thermoplastic starch from cassava bagasse and cassava starch and their blends with poly (lactic acid), Published on 5 January 2012, doi: 10.1016/j.indcrop.2011.11.036.

TRENDS AND CURRENT ISSUES OF MAG WELDING OF MILD STEEL

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Nowadays, steel production industry plays a very important role in economy. Steel manufacturing companies that produce steel structures have increased production in recent years, providing jobs for thousands of people and a large contribution to GDP as a whole. Metal processing companies use various technologies for the production of steel products. One of these technologies is welding.

Most of the steel constructions are made of structural steel such as S235, S275, and S355. Various production technologies are used in its processing, but one of the most commonly used arc welding technologies is semi-automatic or MAG (Metal Active Gas) welding. It is one of the most productive welding methods and has a universal application using both mechanized and robotic equipment as well as being the most common method in manual welding.

In order to make the MAG welding process more productive and easier to control, various types of welding wires have been developed, and the equipment has changed significantly in recent decades. This allows the process to be done easier and also increase the ability to control the welding process and course way much better. The choice of the shielding gas has become wide in recent decades, too. This is one of the issues that has made it possible to improve welding processes as well as weld various alloy steels and various metal alloys.

The welding process and raw materials, including shielding gas, can affect the quality and strength of the weld. Several studies have been conducted to find solutions for welding low-alloyed steels to prevent the formation of pores, spatter, microcracks and unwanted inclusions in welds that make them less durable. It is stated in various scientific studies that welding of low-alloy structural steels [1], [2], increase the percentage of CO_2 (carbon dioxide) (from 20 % to 25 %) in a mixture with Argon (Ar), the metal structure of the weld does not differ significantly from the base material structures, with different types of inclusions (small micro-granules) being smaller [3]. Studies [1]–[3] have concluded that welding with shielding gas containing 75 % Argon and 25 % CO_2 is the most efficient.

A completely opposite statement was made in another study [4]. It states that there were more inclusions found in samples welded with gas mixture with a 75 % content of CO_2 in Argon. The less the CO_2 content, the smaller was the diameter of the inclusions in this welding joint. It was also stated that the diameter of the inclusions is smaller by using gas mixture with 92 % Argon and 8 % CO_2.

There are also different views about the structure of the welding joint when different shielding gases are used in MAG welding. It is possible to find in older articles that the gas mixture with less content of CO_2 makes the bigger grain structure compared to the one that is welded with gas mixtures containing less Argon. There is also an article [5] showing that the welding technologies have changed during last decades and now it is also possible to achieve the structure with smaller grains even when welding is done with Argon mixtures with lower CO_2 content and even with short arc parameters.

The studies related to low-alloy structural steel (up to 420 MPa) have all been related to MAG welding with short arc parameters. Therefore, it is necessary to study welding with jet transfer parameters and the effect of shielding on the welding process of low alloyed steels.

References

1. P. Kah & J. Martikainen, Influence of shielding gases in the welding of metals, 2011.
2. Ebrahimnia M., Goodarzi M., M. Nouri, and M. Sheikhi, Study of the effect of shielding gas composition on the mechanical weld properties of steel ST 37–2 in GMAW 2009.
3. Ramy Gadallah, Raouf Fahmy, Tarek Khalifa, Alber Sadek, Influence of Shielding Gas Composition on the Properties of Flux-Cored Arc Welds of Plain Carbon Steel, 2012.
4. Moreira, A. F.; Gallego, J.; Tokimatsu, R. C. & Ventrella, V. A. The effect of shieliding gas mixture on inclusion distribution for MIG welding process, 2006.
5. Boiko, I., Avišāns, D. Study on Shielding Gases for MAG Welding. Materials Physics and Mechanics, 2013, Vol. 16, No. 2, pp. 126–134. ISSN 1605-8119.

PAAUGSTINĀTAS IZTURĪBAS TĒRAUDU (650 MPA) *MAG* METINĀŠANAS AKTUALITĀTES

CURRENT ISSUES OF MAG WELDING OF HIGH STRENGTH STEEL OF 650 MPA GRADE

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Pēdējo gadu laikā metālapstrādes uzņēmumu saražoto metāla konstrukciju un izstrādājumu skaits ir ievērojami palielinājies. Neskatoties uz metāla izejmateriālu cenu būtisku pieaugumu, daudzi metālapstrādes uzņēmumi ir spējuši rast jaunus pasūtījumus un nodrošināt darba vietas savu uzņēmumu darbiniekiem. Lai spētu noturēt esošo tirgus daļu un arī iegūt jaunus klientus, uzņēmumi sastopas ar dažāda veida izaicinājumiem. Viens no tiem ir jauni materiāli, piemēram, paaugstinātas stiprības tēraudi, kas atšķiras pēc savām īpašībām no ierastajiem konstrukciju tēraudiem *S235* un *S355*, ko daudzi uzņēmumi apstrādā ikdienā.

Tāpat kā konstrukciju tērauda izstrādājumu izgatavošanā tiek izmantota lok-metināšanas tehnoloģija, arī paaugstinātas izturības tēraudu savienošanā visbiežāk tiek izmantota tieši pusautomātiskā jeb *MAG* metināšana (*Metal Active Gas*). Tā joprojām ir viena no universālākajām un efektīgākajām metināšanas metodēm, kas tiek izmantota metālapstrādes uzņēmumos Latvijā.

Lai arī paaugstinātas izturības tēraudi līdzinās konstrukciju tēraudiem *S235* un *S355* pēc to izskata, kā arī daudzām citām īpašībām, piemēram, noturība pret mitrumu, tomēr to ķīmiskais sastāvs ir atšķirīgs, līdz ar to atšķiras arī apstrādes īpatnības. Arī metināšanas aizsarggāzu vidē var ieviest dažādas korekcijas, jo rodas nepieciešamība izmantot cita veida stiepli, kas pēc ķīmiskā sastāva līdzinās pamatmateriālam. Tomēr joprojām aktuāls jautājums ir par aizsarggāzes izvēli, jo arī tā ir būtiska *MAG* procesa sastāvdaļa.

Ir veikti dažādi pētījumi par konstrukciju tēraudu metināšanu aizsarggāzu vidē. Dažādi avoti liecina par to, ka nepieciešams izmantot argona un CO_2 maisījumus, lai uzlabotu metināšanas kvalitāti, kā arī neradītu būtiskas atšķirības gan ķīmiskajā sastāvā, gan materiālu izturībā starp sametināto šuvi un pamatmateriālu. Lai arī ir veikti vairāki pētījumi par paaugstinātas izturības tēraudu (950 MPa līdz 1000 MPa) metināšanu un aizsarggāzes izvēles uz procesu, līdz šim nav atrasta informācija par materiāliem, kas ir starp stiprību 355 MPa un 950 MPa.

Tika veikti izmēģinājumu testi un sametināti vairāki paraugi no paaugstinātas izturības tērauda materiāla (650 MPa), lai noskaidrotu un pārbaudītu dažādu aizsarggāzu ietekmi uz metināšanas procesu un arī sametinātās šuves fizikālajām un ķīmiskajām īpašībām. Atšķirībā no iepriekš veiktajiem un apskatītajiem pētījumiem šajos izmēģinājumos tika metināts, izmantojot strūklveida materiāla pārnesi, kad metināšanas elektrods pāriet metināšanas vannā nevis pilienu veidā, bet gan nelieliem nepārtrauktiem pilieniem, nodrošinot stabilu metināšanas intensitāti un mazākas šļakatas jeb nesakusušā metāla šļakstīšanos metināšanas zonā.

Pētījumā tika izmantotas vairākas Latvijas un Baltijas tirgū pieejamas aizsarggāzes, kas tiek plaši izmantotas dažādos ražošanas uzņēmumos. Viena no izmantotajām aizsarggāzēm ir ogļskābā gāze, ko metināšanā kādu laiku tik plaši vairs neizmanto, neskatoties uz tās zemo cenu un plašo pieejamību. Tika arī izmantoti vairāki aizsarggāzu maisījumi – Ar + CO_2 (8 %, 18 %, 25 %), kā arī Ar + CO_2 (5 %) + O_2 (5 %).

Kā vienu no vislabākajiem maisījumiem, ko apraksta vairākos ārvalstu pētījumos, *MAG* metināšanai norāda argona un CO_2 25 % maisījumu. Kā iepriekš minēts, šajos pētījumos process tiek pētīts, strādājot īsajā lokā, kad stieples pārnese metināšanas vannā notiek pilienu veidā. Metinājuma veidošanās uzlabojas, izmantojot maisījumus Ar + 20 ... 25 % CO_2, un tas ir novērojams visdažādākajos režīmos. Šuves augstums ir ievērojami zemāks nekā tad, ja tiek metināts ar tīru CO_2 [1]. Lai arī dažādos pētījumos, kuros metināts konstrukciju tērauds *S235* vai *S355*, tiek uzsvērts, ka ar šo aizsarggāzi ir iespējams metināt vienādi labi gan īsajā lokā, gan strūklveida pārneses režīmos, tomēr veiktie izmēģinājumi parādīja pretēju rezultātu, un sametinātās šuves katete veidojās augstāka un šļakatu apjoms metināšanas zonā veidojās lielāks.

Kā viens no izplatītākajiem aizsarggāzu maisījumiem ražošanā bieži vien tiek izmantots Ar maisījums ar 18 % CO_2 sastāvu. Par vienu no priekšrocībām šādam maisījumam tiek minēts plašais režīmu diapazons. Izmantojot to, ir iespējams izvairīties no argonam raksturīgās pirksta formas caurkausējuma veidošanās, kas izraisa nepietiekamu sakausējumu un poru skaita palielināšanos, kā arī no šaura un dziļa caurkausējuma formas, kas raksturīga oglekļa dioksīdam un ir bīstama ar iespējamu plaisu veidošanos šuvēs [2]. Metinot ar šo aizsarggāzu maisījumu, tika sasniegti optimāli metināšanas parametri, šļakatu daudzums bija pieņemams, kā arī šuves katetes augstums tika izturēts, neveidojās palielināts uzkausējums, salīdzinot ar iepriekšminēto maisījumu.

Pretrunīgi tiek vērtēts Ar + CO_2 8 % maisījums konstrukciju tēraudu metināšanā. Kā viens no trūkumiem tiek izcelts šī maisījuma sniegums, metinot īsajā lokā, ar loka nestabilitāti un vājo īssavienojuma veidošanās potenciālu. Kādā no pētījumiem ir teikts, ka, samazinoties CO_2 koncentrācijai aizsarggāzes maisījumā, palielinās dažādu iekļāvumu skaits [1]. Veiktajos eksperimentos ar Ar + CO_2 8 % maisījumu tika sasniegti vislabākie rezultāti – stabils metināšanas loks, metināšana bez šļakatām, sametinātās šuves izmēra un formas izturēšana.

Vismazāk pētīta ir aizsarggāzes, kuras sastāvā ir Ar + CO_2 5 % + O_2 5 %, izmantošana. Tikai viens no atrastajiem avotiem nosauc šāda tipa aizsarggāzes priekšrocības. Metinot oglekļa un mazleģētos tēraudus ar metināšanas stiepli, kuras sastāvā ir mangāns un silīcijs, ir iespējams sasniegtas tādas priekšrocības kā mazāks šļakatu daudzums, labāks šuves izskats, samazināta tendence veidot šuvēs poras un plaisas, pretēji procesam, salīdzinot ar CO_2 metināšanu [1]. Metinot ar šo aizsarggāzi paaugstinātas izturības tēraudu paraugus, tika novērots, ka metināšanas vanna ir ļoti šķidra, kas izraisa šuves notecēšanas tendenci, veidojot nelielu formas ieliekumu. Vēl tika novērots, ka pēc metināšanas, šuvei atdziestot, uz tās virskārtas izveidojas kristālisks pārklājums. Tiks veikts padziļināts pētījums, lai noskaidrotu, kāda veida pārklājums tas ir, kāds ir tā ķīmiskais sastāvs, kā arī – kas ir šī pārklājuma veidošanās iemesls.

Pateicība

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Informācijas avoti

1. P. Kah & J. Martikainen, Influence of shielding gases in the welding of metals, 2011.
2. Свецинский В. Г., Римский С. Т., Галинич В. И. Сварка сталей в защитных газовых смесях на основе аргона в промышленности Украины //автомат. сварка. – 1994.

CHAOTIC CHANGES IN THE PROPERTIES OF SECONDARY MATERIALS

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Recent studies of product lifecycle and current situation in the use of recycled materials led to a decision to start investigating the reasons for a low level of recycling and reuse [3]–[4]. According to EPA (Figure 1) only 7 % of plastic waste is being recycled [1].

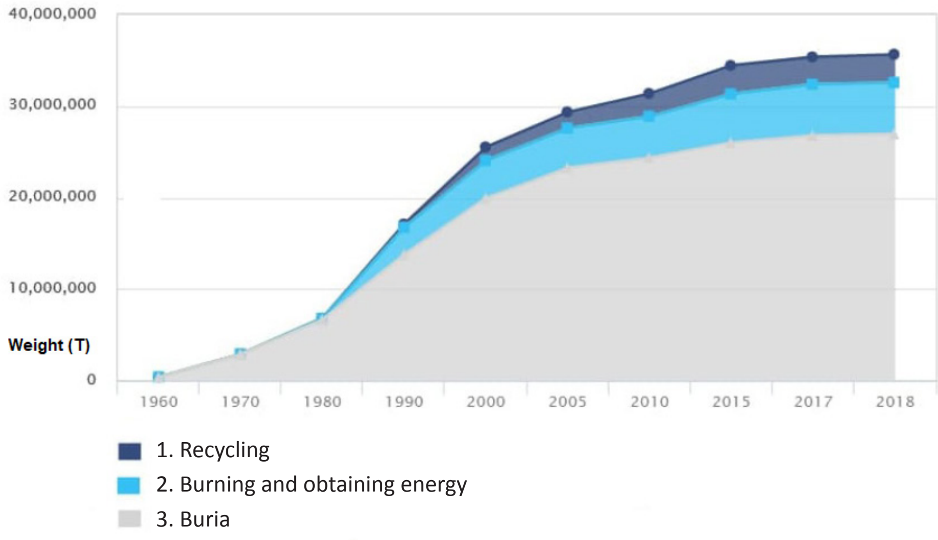

Figure 1. Recycling of plastic waste in the USA.

In this paper, we investigate three groups of automotive spare parts made from recycled materials and their failure. The statistics of failure (Figure 2) collected for the products made of 3 groups of materials (ZAMAK, ABS, PVC) in a two-year period of product exploitation are presented.

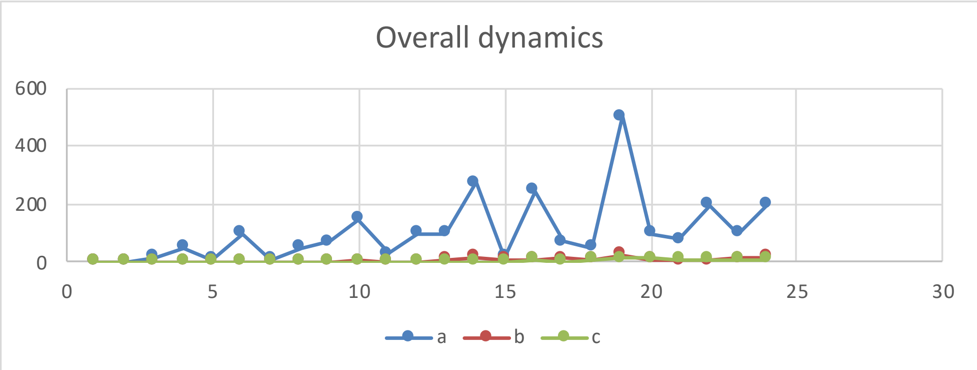

Figure 2. Statistics of failure, where a – ZAMAK, b – ABS, c – PVC.

Herewith we provide an overview on the investigated features and specifications of those materials with regard to their capability and applicability for recycling and reusing in further production and give respective conclusions for general approach to the product lifecycle and material reuse [1]–[4].

References

1. Franz Josef Maislinger. Leichtbaupotenziale unter Verwendung hochfester metallischer Werkstoffe für Automobil- und Luftfahrtanwendungen, FH OÖ Studienbetriebs GmbH - Fakultät für Technik/Umweltwissenschaften, 2018.
2. Bangel, M., Hornborstel, N.: Die Karosserie des neuen Audi-TT – Intelligenter Mischbau erfordert innovative Fügeverfahren. 13. Paderborner Symposium Fügetechnik, S. 181–188 (2006).
3. V. Mitrofanovs, I. Boiko and Ē. Geriņš. New approach for recycling spare parts, components and assemblies, . Agronomy Research, 2020.
4. V. Mitrofanovs, I. Boiko, E. Gerins. Management of parts and components for units and assemblies in mechanical engineering industry and its impact on the environment. Agronomy Research, 2019.

POSSIBILITIES OF EFFICIENT USE OF TAPE METAL STAMPING WASTE

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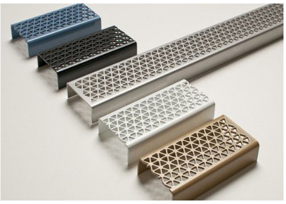
In mechanical engineering, a fairly large amount of metal perforated waste (MPW) is often generated, which is created as a result of stamping or cutting of small-sized parts. One of the striking examples is the formation of MPW during stamping of drive chain elements (Figure 1). There are a number of specialized enterprises in the world where hundreds of tons of such waste are generated per year.

The advantage of such materials is their high physical and mechanical properties, since the material is designed to work under significant mechanical stress and friction. It should be noted that the material in this case is quite homogeneous, and the length of tape can reach up to hundreds of meters.

a

b



c

Figure 1. Solid steel tape entering the stamping press (a), perforated tape (b), and profile scrap (c).

One of the areas of secondary use of MPW after stamping is material melting. However, this technology is not optimal. There are many downsides here. When melting thin sheet metal, a large waste of metal is observed. In addition, the material must be cleaned of oil prior to melting, but some of them have a high melting point (energy-intensive for recycling) Therefore, finding the most profitable use of perforated waste is an important task from the viewpoint of technology and economics. The material is very valuable, it can and should be used more efficiently in construction, mechanical engineering and other industries. The geometrical and mechanical properties of MPW are varied and this expands the possibilities of using this material.

The paper considers the geometrical parameters and mechanical properties of MPW, various possibilities of reuse, as well as economic indicators for reuse of several types of perforated steel belts.

References

1. Lisicins, M., Mironovs, V., Kalva, L. Analysis of Perforated Steel Tape Usage Possibility in Construction// Proceedings of 3rd Int. Scientific Conference "Civil Engineering'11". Latvia, Jelgava: LLU izdevniecība, 2011, pp. 95–102. ISSN 2255-7776.
2. Mironovs, V., Lisicins, M., Boiko, I. Manufacturing of Cellular Structures of the Perforated Steel Tape// Proceedings of 8th International DAAAM Baltic Conference "Industrial Engineering". Estonia, Tallinn, 2012, pp. 688–693.

PROSPECTS FOR THE MANUFACTURE OF CONSTRUCTION FITTINGS FROM TITANIUM

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It is planned to replace the reinforcement of reinforced concrete (titanium concrete) with titanium in order to expand the use in construction of titanium obtained using a new technology, which was researched and approved by the ERDF Project No. 1.1.1.1./16/A/85 "Electroslag process for better titanium deposition morphology". The technology for obtaining titanium and titanium alloys and semi-finished products from them allows production in small and medium-sized enterprises, similar to foundry work in an industrial enterprise [1].

The use of titanium will allow to change some parameters of titanium concrete structures compared to reinforced concrete structures. The protective layer of concrete, which serves to protect the reinforcement from the external environment, will be significantly reduced. This will contribute to the reduction of the weight of concrete structures, while maintaining the strength properties, and will allow to create lighter structures that will be able to withstand higher loads.

Figure 1. Testing process for concrete blocks with titanium reinforcement.

Acknowledgements

This work has been supported by the ERDF funded project No. 1.1.1.1./16/A/85 "Electroslag process for better titanium deposition morphology".

References

1. Platacis E., Kaldre I., Blumbergs E., Goldšteins L., Gailītis K. Optimization of electroslag melting towards to titanium morphology improvement in combined Kroll process. *COMPEL.* 2019, 12; doi: 10.1108/COMPEL-05-2019-0198.

INSTALLATION OF IMPACT GRINDING OF CADMIUM BATTERIES WITH MAGNETIC SEPARATION

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Project lzp-2018/1-0415 "Investigation of the method for recycling cadmium containing industrial batteries and small consumer cells through electroslag remelting for recovery of metallics in an environmentally sound manner" proposed a method aimed at recycling cadmium-containing storage batteries and small batteries. The method assumed electroslag remelting of pre-crushed cadmium-containing batteries. The cadmium in batteries is a cadmium/cadmium oxide powder. The reduction of cadmium by carbon from the cadmium oxide during electroslag remelting ensures maximum extraction of cadmium from secondary waste.[1]

To increase the efficiency of electroslag remelting (excluding the metal body and metal parts of cadmium batteries from the process), a drum grinder with magnetic separation of crushed cadmium batteries is used.

Figure 1. Installation of impact grinding of cadmium batteries with magnetic separation.

Acknowledgements

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References

1. Blumbergs E., Serga V., Platacis E., Maiorov M., Brekis A., Shishkin A. A Sustainable Approach for Cadmium Recovery from Oxide Using Molten Salt Slag. *Metals.* 2020, 10, 981; doi:10.3390/met10070981.

MAŠĪNBŪVES RAŽOŠANAS ROBOTU TEHNOLOĢISKĀ KOMPLEKSA PROJEKTĒŠANAS OPTIMIZĀCIJA

OPTIMIZING THE DESIGN OF THE ROBOT-TECHNOLOGY COMPLEX OF A MACHINE- BUILDING ENTERPRISE

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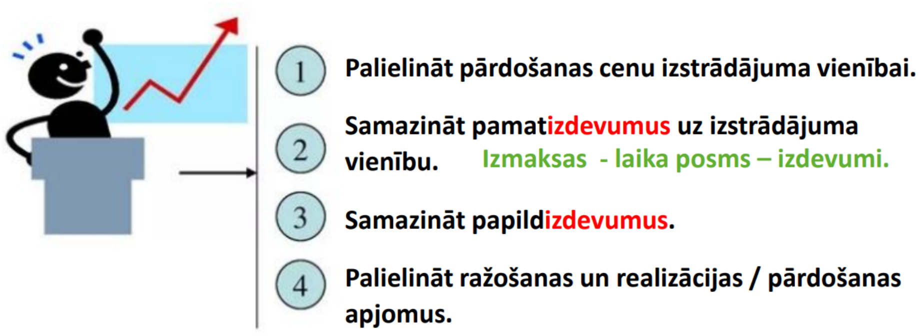
Pāreja uz tirgus ekonomiku ievērojami samazināja tehnoloģisko procesu automatizācijas līmeni. Lielie izdevumi, kas saistīti ar jauno iekārtu piegādi, izstrādājumu izlaides programmas nepietiekams apjoms un mūsdienīgo izmaksu novērtēšanas metodikas neeksistēšana izraisa krasu intereses samazināšanos saistībā ar automatizācijas problēmām.

Eksistē četri pamata paņēmieni, kā var palielināt ražotnes ieguvumus (1. att.):



1. att. Četras stratēģijas ražotnes ieguvumu palielināšanai.

Pētījuma mērķis – piedāvāt tehnoloģijas projektēšanas metodiku ar automatizācijas līdzekļu izmantošanu. Uzdevums – palielināt ražotnes ieguvumus, palielinot ražošanas un realizācijas apjomus. To var veikt, pirmkārt pieņemot darbā papildu darbiniekus – palielinot darbinieku štatu, otrkārt, iegādājoties ražošanas robotu un izveidojot robotu tehnoloģisko kompleksu (RTK).

RTK iekļauj trīs komponentus:

1) ražošanas robotu;
2) tehnoloģisko iekārtu;
3) tehnisko aprīkojumu.

Pirms RTK projektēšanas un ieviešanas detalizēti jāizanalizē, jānovērtē un jāizlabo izstrādājuma ražošanas tehnoloģiskums, materiāltehniskās bāzes līmenis, personāla profesionālā atbilstība jaunākajām prasībām.

Informācijas avoti

1. Mašīnbūves elastīgās automatizētās ražošanas projektēšanas pamati / N. Mozga, A. Kamols – R.: RTU, 2006. – 90 lpp.

TIPVEIDA DAUDZDZĪVOKĻU DZĪVOJAMO MĀJU "LĒTIE" UN "DĀRGIE" ENERGOEFEKTIVITĀTES LĪMEŅA PALIELINĀŠANAS PASĀKUMI

"CHEAP" AND "EXPENSIVE" METHODS OF INCREASING ENERGY EFFICIENCY IN MASS CONSTRUCTION OF MULTI-APARTMENT BUILDINGS

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Lielas enerģētisko resursu rezerves var slēpties tādu daudzdzīvokļu dzīvojamo māju ekspluatācijā, kurām ir labas siltumtehniskās īpašības jeb augsts energoefektivitātes līmenis. Pakāpeniski palielinot prasības pret ēku norobežojošo konstrukciju siltuma aizsardzību, tiek sekmēta paššaprotama nepieciešamība uzlabot un pilnveidot mezglus jeb konstruktīvo elementu sadurvietas, kas arī veido visnopietnākās siltuma zudumu zonas. Šādu zonu identificēšana un veiksmīga siltuma noplūdes likvidēšana ir iespējama, tikai pamatojoties uz siltuma lauku analīzi.

Šajā gadījumā siltuma lauks ir temperatūras sadalījums uz norobežojošās konstrukcijas plakanā šķērsgriezumā, kas veidojas, ņemot vērā temperatūras starpību starp āra telpas un iekštelpas gaisa temperatūru. Protams, katrai ēkai šāds temperatūras lauks būs atšķirīgs, jo to ietekmē virkne klimatisko, siltumfizikālo, celtniecības parametru. Savukārt ēkām, kas ir būvētas pēc vienotiem principiem, it īpaši – veido vienotu sēriju, šādi parametri un to uzlabošanas paņēmieni būs vienādi.

Vispārējo gadījumu jeb temperatūru pārrēķinu, kad temperatūras kritums ir vienāds ar $t_{iekš.} - t_{ārp.} = 10\,°C$ uz aprēķināto temperatūras kritumu $(t_{iekš.} - t_{ārp.})_{apr.}$, apraksta, izmantojot formulu:

$$\tau_i = \frac{(t_{iekš.} - t_{ārp.})_{apr.}}{(t_{iekš.} - t_{ārp.})_0} \tau_0 + t_{ārp.},$$

kur

τ_i – punkta nosakāmā temperatūra;
$(t_{iekš.} - t_{ārp.})_0$ – temperatūras kritums vispārējā gadījumā;
τ_0 – tā paša punkta temperatūra, kas iegūta vispārējam gadījumam [1].

Temperatūras laukus galvenokārt ir jānosaka ēku konstruktīvo elementu pamatmezgliem:

1) ārējo sienu paneļu vertikālajām sadurvietām starpsienu pieskaru zonās;
2) ārējo sienu paneļu horizontālajām sadurvietām pārsegumu balstīšanas zonās;
3) ārējo sienu paneļu vertikālo stūra sadurvietu zonās;
4) ārējo sienu paneļu horizontālajām sadurvietām balkonu paneļu balstīšanas zonās;
5) logu ārējām un iekšējām virsmām [1].

Veiksmīga temperatūras lauka un to parametru definēšana ļauj pārliecināties, vai norobežojošās konstrukcijas atbilst dažādiem būvnormatīviem – gan tiem, kas bija spēkā ēkas celtniecības un nodošanas ekspluatācijā laikā, gan arī modernajām prasībām energoefektivitātes jomā. Divi noteicošie parametri ir temperatūras kritums un kondensāta veidošanas nosacījumi jeb rasas punkts.

Latvijā izplatītas 101., 335., 464., 467., 467a., 103., 104., 602. un 119. sērijas tipveida mājās atšķiras pēc konstrukcijas, izmantotajiem celtniecības materiāliem, būvdarbu veikšanas kvalitātes un citiem parametriem. Temperatūras lauku un to raksturojošo parametru noteikšana ļautu gan dzīvokļu īpašnieku kopībām, gan pārvaldniekiem noteikt, kādi daudzdzīvokļu dzīvojamo māju atjaunošanas instrumenti jālieto nekavējoties un kādiem bez nopietnām sekām un problēmām varētu pievērsties vēlāk, pakāpeniski veidojot nepieciešamo uzkrājumu vai iesaistoties vienā no pieejamajām līdzfinansējuma programmām.

Starp "lētiem" energoefektivitātes līmeņa palielināšanas paņēmieniem un siltuma zudumu samazināšanas instrumentiem varētu minēt jau ikdienišķo koplietošanas un privātīpašumu logu, ieejas durvju nomaiņu, lodžiju stiklošanu, apkures sistēmas modernizēšanu koplietošanas telpās un privātīpašumos (nomainot vecus apkures elementus, izveidojot apvadus, aprīkojot ar termoregulatoriem un siltuma uzskaites ierīcēm) [2]. Savukārt kompleksa ēkas siltināšana un renovācija ir dārga metode.

Ņemot vērā pētījuma lielo tautsaimniecisko nozīmi, darbu ir plānots turpināt.

Informācijas avoti

1. Ивашкова В. К. и коллектив авторов. Каталог температурных полей узлов типовых ограждающих конструкций. Москва, Стройиздат, 1980. 111 стр.
2. Rubīna M. Siltumapgāde. Rīga, LZA Fizikālās Enerģētikas institūts, 2002. 171 lpp.

GAISA KUĢU PRIEKŠĒJO ŠASIJU BOJĀJUMU ANALĪZE

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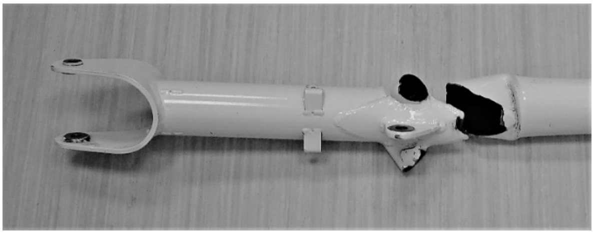
Ekspluatācijas gaitā katrā nosēšanās reizē gaisa kuģu priekšējā riteņa šasija uzņem ievērojamu triecienu. Gaisa kuģa "*SOCATA*" priekšējā riteņa statnē (1. att.), kur vidusdaļā izveidotas vairākas metinātas šuves, ekspluatācijā radušies spriegumi summējas ar tiem esošiem rūdīšanas termiskiem spriegumiem.



1. att. Gaisa kuģa "*SOCATA*" priekšējā riteņa statne.

Blakus šuvei sāk veidoties maza cikla noguruma lūzums, kas vēlāk attīstās tālāk. Tas prasa laiku, un lūzuma virsma paspēj oksidēties. Ja paliekošais veselais statnes šķērsgriezums nevar izturēt nosēšanās reizē radītos spriegumu, notiek sprieguma lūzums. Tā virsma ir gaiša, smalkgraudaina. Statnes aizmugures daļā, kur liece rada spiedes spriegumus, redzama plastiski deformēta daļa (2. att.).

2. att. Gaisa kuģa "*SOCATA*" priekšējā riteņa statne.

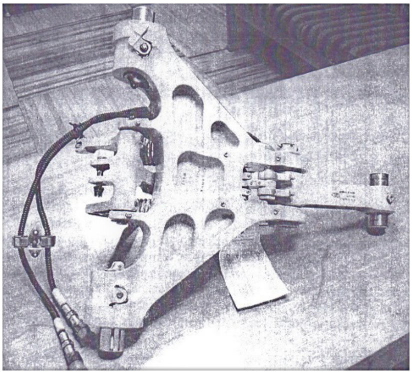
Tālāk tiek saroutas abas sānu atsaites, un priekšējā riteņa šasija beidz darboties. Notiek gaisa kuģu avārija.

Gaisa kuģa "*TECHAM*" gadījumā bojājums radās priekšējā riteņa šasijas balsta atlokā (3. att.).

3. att. Gaisa kuģa "*TECHAM*" priekšējā riteņa šasijas balsta atloks.

Tā bija atlieta no alumīnija sakausējuma. Nosēšanās gaitā caur šasijas horizontālo garenasi tiek noslogoti gala leņķa atloki. Lūzuma sākuma vietā, kur darbojas lieli lieces spriegumi, novērojami nelieli virsmas bojājumi, ieslēgumi un struktūras defekti, kas var izraisīt noguruma lūzumu. Ekspluatācijas gaitā lūzums attīstās pakāpju veidā. Tas ir gluds un spīdīgs. Noguruma lūzums attīstās tiktāl, ka atloka paliekošais šķērsgriezums nespēj uzņemt nosēšanās gaitā radītos spriegumus un notiek kreisā atloka gala noguršana, un balsta konstrukcija pārstāj darboties.

Priekšējā riteņa šasijas mehānisms var pārtraukt darboties, ja tiek traucēta mehānisko daļu savstarpējā kustība. Piemēram, lidmašīnai "*Bombardier Q400*" neizdevās izlaist priekšējā riteņa šasiju. Nācās šo operāciju veikt atkārtoti, līdz izdevās to iekustināt un izlaist priekšējo riteni. Apskatot šasijas fiksācijas mezglu (4. att.), varēja konstatēt, ka apkope veikta nepilnīgi, brutāli bojāti eļļošanas nipeļi, nosista krāsa, eļļa palikusi uz ārējās virsmas.



4. att. Gaisa kuģa "*Bombardier Q400*" priekšējā riteņa šasija.

Secinājumi

1. Gaisa kuģu priekšējā riteņa šasijas lūzumu cēlonis ir nosēšanās operācijā radušies trieciena spriegumi.
2. Ekspluatācijas laikā radušies lūzumi ir ar maza cikla noguruma raksturu, tie attīstās laika gaitā.
3. Lai savlaicīgi konstatētu radušos plaisu, svarīgi ir regulāri veikt atbildīgo mezglu monitoringu – diagnostiku, kā arī regulāri veikt rūpīgu tehnisko apkopi.