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Examination of selected cleaning service equipment in the scope of airfield's movement areas maintenance

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Abstract. Maintaining airport surfaces in good condition and in a good state of cleanliness throughout the year is of extreme importance to ensure the safety of flight operations by aircraft. The use of various equipment is practicable in order to clean regularly all paved surfaces. Components of brushes and plows during operation wear out and must be replaced periodically. New elements should be of adequate quality. Examples of airport cleaners and exchangeable cleaning elements are presented. Some requirements have also been given on the brushes' bristles. To confirm the need to control the purchased cleaning elements, the condition of worn components was checked. The results of laboratory tests of new and used brushes bristles are presented. The tests included microscopic observations, microstructure assessment, tensile strength testing, and microhardness testing. Defects in fixing the bundles of polymer brush bristles during airport exploitation were found. Research on steel wires showed a partial loss of the zinc coating during the brush operation (potential corrosion), lowering the tensile strength and increase the hardness of the wires, which could lead to wires crack and break. The article confirmed the need to control of brushes and plows parameters to ensure their proper quality. Their selected parameters should be controlled during purchase and operation on airfields belonging to the Polish Armed Forces. The impact of deicing agents on the elements mentioned above should also be considered.

Keywords: airfield pavement maintenance, runway brooms, snowplows

1. Introduction

The movement and non-movement airport areas must be clean of any foreign debris (FOD) that cause damage to aircraft or impair the operation of aircraft systems. The provisions of Annex 14 [7] require to take action as necessary to remove snow, slush, ice, standing water, mud, dust, sand, oil, rubber deposits and other contaminants from the movement area as rapidly and completely as possible so as to minimize their accumulation and, thus, to provide good friction characteristics.

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Airfield pavements shall be maintained in good condition in order to ensure aircraft safety [1, 2, 3, 4, 5, 18]. Any damage or deterioration of these pavements could result in severe damage to aircraft engines and propellers and could cause injury to personnel from loose debris thrown by a spinning propeller. In addition to the pavements, foreign object debris (FOD) can be generated from personnel, airport infrastructure (lights, signs), the environment (snow, ice) and the equipment operating on the airfield (aircraft, airport operations vehicles, maintenance equipment).

FOD found on pavements are, among others metal or plastic parts from maintenance equipment. The parts of vehicle cleaning elements found on the surface, e.g. broken brushes bristles, made of steel or plastic, can be sucked in by jet engines or stuck in aircraft tires, which can lead to catastrophic results. In addition, because airport cleaners work at a high rotational speed of brushes (minimum 500 rpm), loose elements or fragments of bristles may pose a threat to airport personnel or equipment operators.

Components of brushes and plows during operation wear out and must be replaced periodically. However, spare parts offered by suppliers are not always of sufficient quality. Inspection of new brushes elements kept in a storage room revealed, among others the presence of corrosion (rust on new steel wires). Defects in fixing the bundles of polymer brush bristles during airport exploitation were found. Therefore, there is a need to analyze the causes of shorter than expected service life of various cleaning elements.

Regular checking of geometry, physicochemical and mechanical parameters of cleaning elements (brushes' components, cutting edges of plows) supplied by different manufacturers or suppliers, will help in the assessment of the process of wear of elements. The article focuses on presenting the testing of airport brushes elements.

2. Airport maintenance equipment

The equipment must be manufactured expressly for airport pavement cleaning [4]. An airport's need can be quite different from highway needs in the same region [1]. Airport terrain is generally flat, the pavement can be very wide, many airports have in-pavement fixtures, the terrain beyond pavement edges must be cleared (runway lights). The snow is not usually very deep, but rapid clearance time is often a strong factor in equipment selection. Safety requirements and testing criteria of machines for road surface maintenance are given in the standards [10, 11, 12].

The airport uses a variety of maintenance equipment to ensure that the airport remains operational. The equipment may be self-propelled or attached to a carrier vehicle. This equipment may include [5, 6, 15, 16, 17]:

- sweeper-blower machines (airport cleaners) – sweeping and cleaning with brushes and a blower (using rotating steel brushes, the cleaner removes dirt from the surface and then rejects it outside the runway,
- compact sweeper-blower - the unit can work simultaneously as a plow, a broom, and a blower),
- airport vacuum cleaning machines - using rotating brushes the cleaner removes dirt from the surface and then sucks it into the tank,
- snow plows - they are most commonly mounted in the front of a carrier vehicle, but they also may be mounted on the side or underneath the vehicle,

- the multi-tasking equipment (MTE) - this type is defined as a minimum plow, broom, and air blast. Other attachments or components such as anti-ice, de-ice systems or underbody scrapers which aid in the snow and ice removal process may be included providing that addition of such devices do not exceed operational capacities and/or parameters of the unit.

The maintenance equipment should be tested by performance tests [15, 16, 17]. According to SAE ARP 5564 standard [17], airport runway brooms are primarily used to clean snow, slush, and ice from the airport runway, taxiway, and ramp areas by using a brush with bristles to clean the surfaces. Other uses of runway broom if specified are: dirt cleanup, cutting ice, rubber removal.

There are many configurations of runway brooms with many different carrier vehicles provided the forward motion for the runway brooms. The front mount type clears snow before passing wheels or plow blades have a chance to compact and push the snow into the grooves and pores of the pavement.

3. Exchangeable brushes components

Components shall be new, unused, of current production [17]. They shall be free of all defects and imperfections that could affect the serviceability of the finished product. Parts that are exposed to wear shall be capable of being replaced.

Examples of brushes mounted on airport maintenance equipment are shown in Fig. 1 [9]. Currently, there are basically two configurations of bristle assemblies: wafers and cassettes (Fig. 2). An advantage of cassettes is that cassettes are easier to replace than wafers since the brush core is not removed from the broom [6, 17].

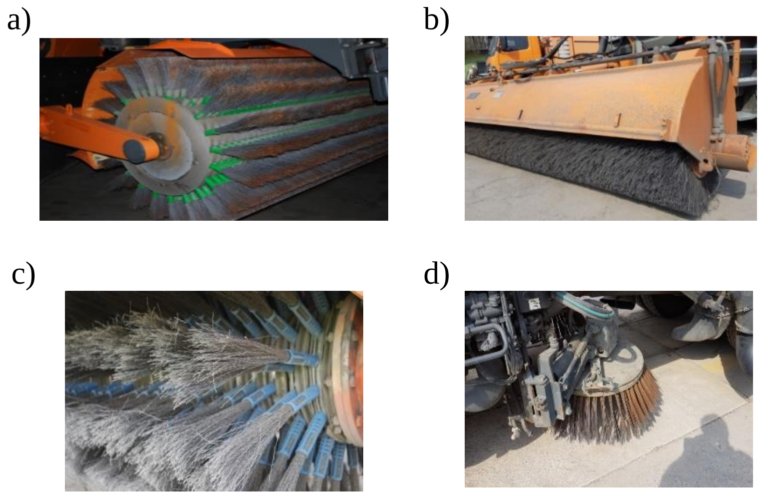


Fig. 1. Maintenance equipment brushes: a) cassette brush, b), c) wafer brushes, d) disc (conical) brush

Source: Author's study on the basis of the Air Force Institute of Technology Archives

In case of wafers (flat or convoluted) the bristles shall be fastened in a radial wafer fashion and shall consist of a steel support ring filled with steel wire bristles or poly-propylene (poly) bristles or with both poly and wire bristles. Regarding the cassettes shall be fastened in a lengthwise fashion and shall consist of a plastic or metal support bar with steel wire bristle or a polypropylene (poly) bristles.

The bristles for the brush shall be designed for runway operation and shall with-stand the normal operation of the broom [17]. They shall be made with adequate retention to keep the bristle from falling out, fatigue strength to keep them from breaking and wear resistance for acceptable life. The bristles shall withstand storage and operating temperatures without functional degradation due to the environment.

The wire bristles shall be crimped and made of zinc galvanized drawn steel wire [16, 17]. The poly bristles shall be made from extruded and pulled strands. The material shall be virgin polypropylene with a UV inhibitor.

The disc (conical) brush (Fig. 2e) and roller brush (Fig. 2f) are designed to mounting on vacuum cleaners.

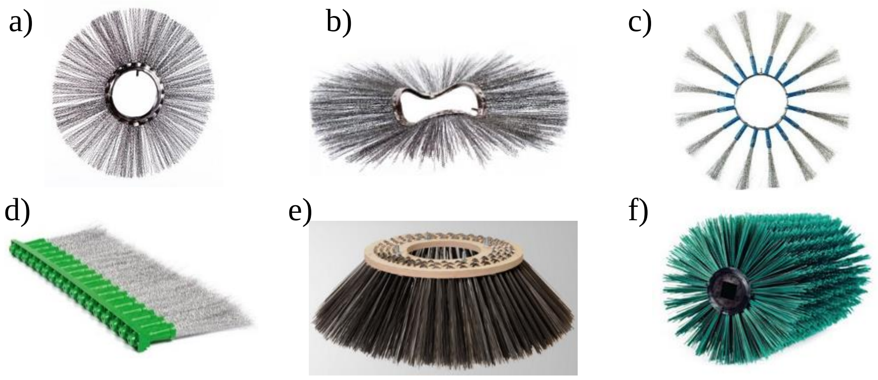


Fig. 2. Exchangeable brushes components [19, 20]: a) flat wafer, b) convoluted wafer, c) flat wafer with tufted wire, d) cassette, e) disc (conical) brush, f) roller brush

4. Laboratory tests

4.1. Samples

Samples were crimped steel wires taken from a new and used cassette for CJS 914S Super II cleaner. The way of taking samples of wires from cassettes is shown in Figure 3.

Moreover, polymer bristles were taken from a damaged brush (Fig. 4). Damage to the brush appeared during the operation of the equipment and resulted from improper quality of the wafers. Defects in fixing the filling in the ring have been found, resulting in bristle loss and breaking.

4.2. Test methods

The microscopic analyses of plastic and steel bristles were carried out in the Institute of High-Pressure Physics, Polish Academy of Sciences, in the Zeiss-SUPRA scanning electron microscope of Zeiss company. For selected micro areas, the microanalyses were implemented with the use of a microanalyzer of Bruker company, Quanta 400 model.

a) b)

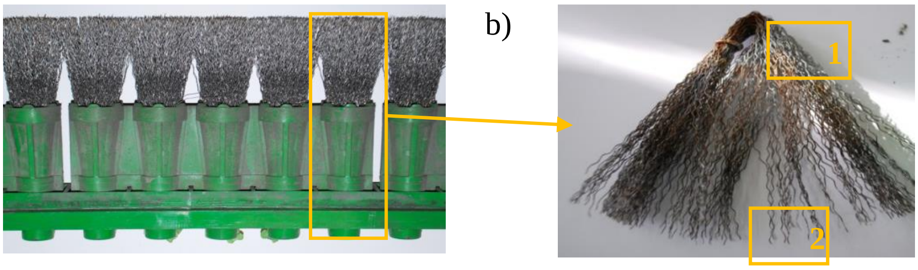
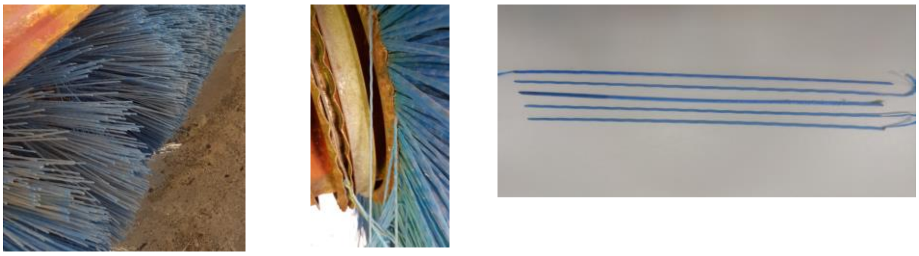


Fig. 3. The way of taking samples of wires from cassettes: a) used cassette, b) a bunch of wires removed from the bush (the numbers indicate locations, where the microanalysis of the wires was performed)



a) b) c)

Fig. 4. Taking samples of bristles from damaged wafer brush: a) brush, b) damaged wafer (bristles fixing defects in the ring resulting in bristle braking), c) broken bristles

Strength tests, microhardness measurements and metallographic examinations [8] were carried out in the Military University of Technology. Metallographic examinations were carried out using the SEM Quanta FEG of the FEI company.

The basic strength properties of wires and plastic bristles were determined according to PN-EN ISO 6892-1:2010 standard, method B [13]. The tensile strength tests were carried out using the universal testing machine INSTRON 8501 (software Series IX), equipped with a force measuring head with a range of up to 5 kN. During the tensile testing, changes in the value of the loading force were recorded automatically. On the basis of the obtained sets of measuring points, in the case of bristles made of plastic, the tensile strength and elongation were determined. Due to the shape of the steel wires (waved) elongation at break results provided for information only. The distance between the clamps was 70 mm, displacement speed: 4 mm/min.

The microhardness measurements were made according to PN-EN ISO 6507-1:2018-05 standard [14], by a Shimadzu microhardness tester using 100 G load.

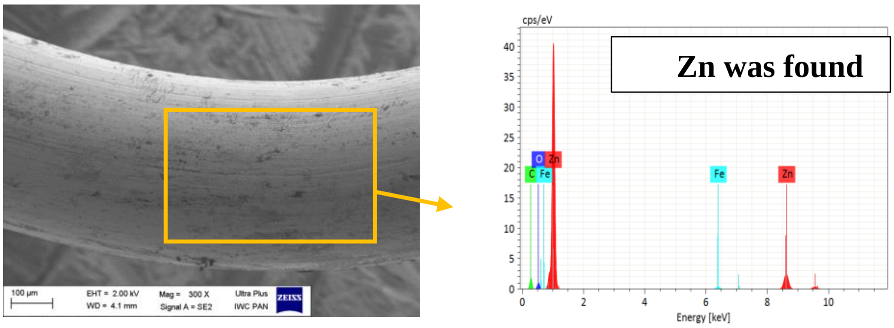
4.3. Test results

Scanning microscopy

The surface wire layer was subject to the observation in SEM. The observations of wires were made in terms of the presence and quality of the coating. The microstructure of surfaces of the selected wire samples together with the X-ray microanalysis data (Energy Dispersive X-ray Analysis) of chosen micro areas of surfaces was shown in figures. The observations were of descriptive rather than quantitative character. The new wire surface is shown in Figure 5. Figure 6 and Figure 7 relate to the used steel wire sample (location No.1 and No.2 in Figure 3). The microscopic observation was carried out in the conditions of the high vacuum and accelerating voltage of 15 kV.

The evaluation of the microstructure was also performed on a plastic bristle surface and shown in Figure 8.

a) The new wire



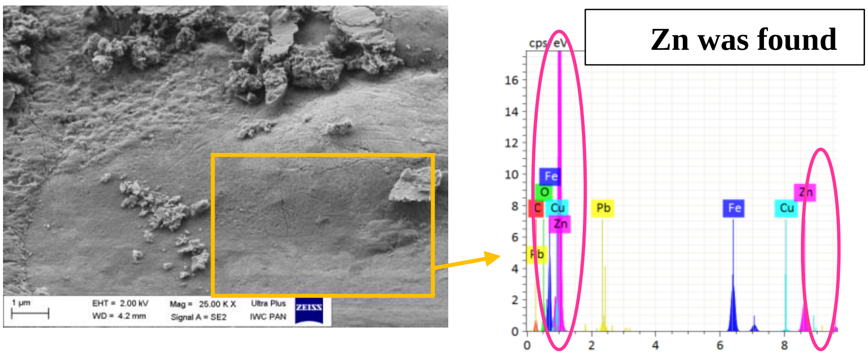
a) b)

Fig. 5. The new wire: a) view of the surface, b) microanalysis of the wire surface (EDS), presence of a zinc coating

According to [16] and [17], the wire bristles shall be made of zinc galvanized drawn steel wire. On the surface of the new wire, there is a uniform, continuous zinc coating with few discontinuities.

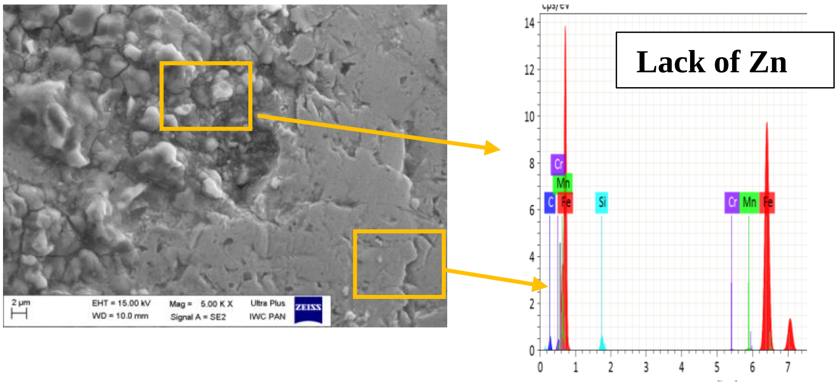
b) The used wire

On the surface of the used wire, there are numerous traces of exploitation in the form of corrosion deposits, abrasions and plastic deformation of the coating.



a) b)

Fig. 6. The used wire - the place within the sleeve, marked No.1 in Figure 3:
a) microstructure of the surface, b) microanalysis (EDS) of the micro area of the surface, presence of a zinc coating



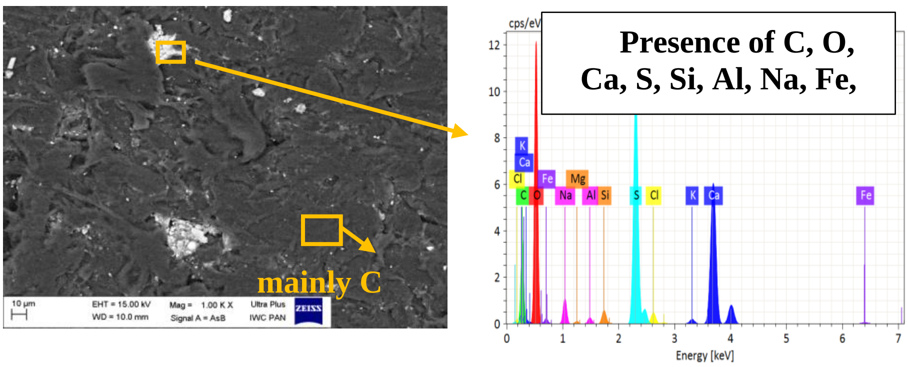
a) b)

Fig. 7. The used wire - the place out of the sleeve, marked No.2 in Figure 3 (contact wire and pavement): a) microstructure of the micro area of the surface, b) microanalysis of the sample surface (EDS), no zinc coating

The results of X-ray microanalysis of the wire taken from the used cassette indicate the presence of Zn within the bunch placed in the sleeve and its absence in the contact area with the pavement. The lack of zinc coating results from abrasion during the operation of maintenance equipment. Taking into account the pH of the de-icing agents used at airports, it is assessed that they may also affect the zinc coating. De-icing agents commonly used at airports in Poland are based on sodium acetate, potassium acetate, sodium formate, and potassium formate. The pH of water solutions of such agents can reach up to 12.

c) <u>The plastic bristle</u>

Microscopic observations of polymer bristles indicate the presence of contaminants in the plastic material, which may come from the production process or foreign particles that have been pressed into the material during the operation of the equipment.

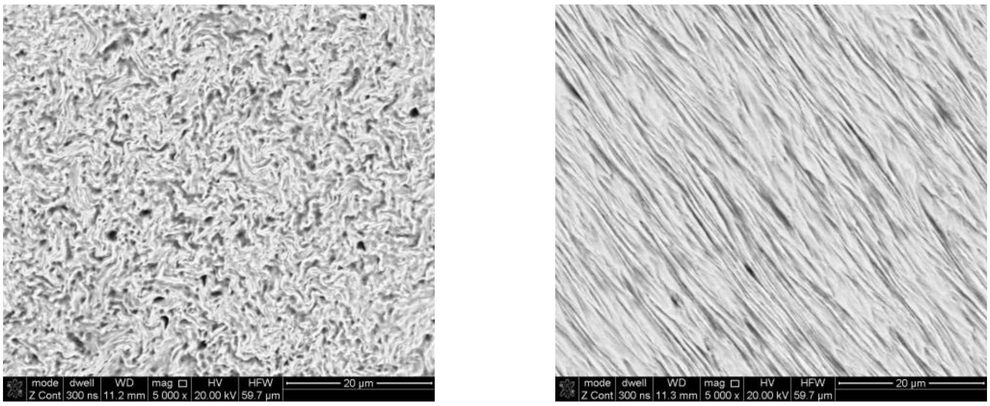


a) b)

Fig. 8. Polymer bristle: a) microstructure of polymer bristle material, b) microanalysis of the sample surface (EDS)

Metallographic examinations

Testing was carried out on samples prepared in the form of metallographic microsections. Typical microstructures of the new and used samples are shown in Figure 9 [8].



a) b)

Fig. 9. A typical microstructure of both: a) the new, and b) the used sample, SEM/BSE, x5000 magnification, 20 kV

As a result of structural investigations, it was found that both examined wires (new and used) are characterized by a similar microstructure of fine perlite with elongated grains formed as a result of the drawing.

TENSILE STRENGTH

Steel bristles

The tensile strength results of the used wires are listed in Table 1, and the results of the new wires - in Table 2. Load-elongation curves of wires taken from the new and used cassettes are shown in Figure 10.

According to [16], [17] the wire bristles shall have a minimum diameter of 0.0165 to 0.0180 inch (from about 0.419 mm to 0.457 mm) nominal with a minimum tensile strength of 325 000 pounds per square inch (psi) - about 2240 N/mm^2.

Table 1. Tensile test results of the used wires

Specimen's number	Breaking load [N]	Elongation at break [mm]	Tensile strength R_m [MPa]
z-x1	314	10	2066
z-x2	296	9	1948
z-x3	312	8	2053
z-x4	356	10	2342
z-x5	336	9	2211
Mean value	**323**	**9**	**2124**

Table 2. Tensile test results of the new wires

Specimen's number	Breaking load [N]	Elongation at break [mm]	Tensile strength R_m [MPa]
n-x6	363	13	2389
n-x7	354	11	2329
n-x8	362	11	2382
n-x9	352	11	2316
n-x10	383	13	2520
Mean value	**363**	**12**	**2387**

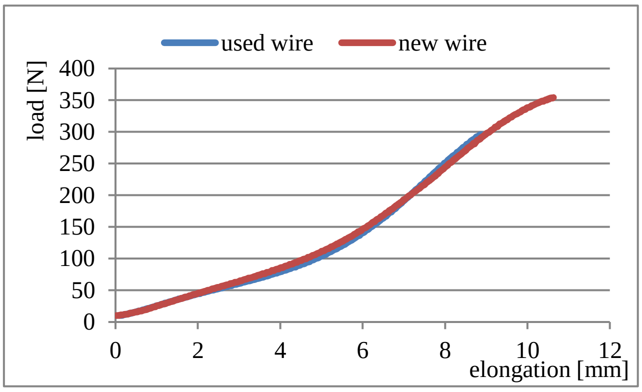


Fig. 10. Load-elongation curves of wires taken from new and used cassettes

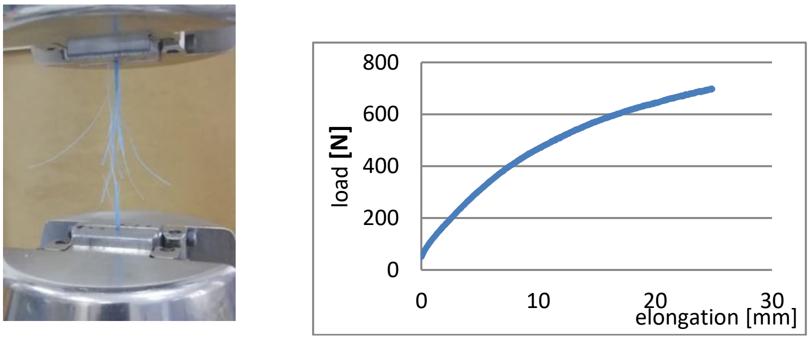
The tensile strength of the new wire (Table 2) is 2387 MPa and corresponds to the strength of the SM or DM spring wire (2250-2520 MPa) with a thickness in the range of 0.40-0.43 mm. The tensile strength of the used wire (2124 MPa, Table 1) is lower than the strength of the new wire by 11% and lower than the required (2240 MPa) in accordance with SAE ARP 5564.

Plastic bristles

The tensile strength results of the plastic bristles are presented in Table 3 and illustrated graphically in Figure 11. The tensile strength of the plastic bristles is 261 MPa, while the required value according to SAE ARP 5564 is 33 MPa.

Table 3. Tensile test results of the polymer bristles

Specimen's number	Thickness [mm]	Width [mm]	Breaking load [N]	Elongation at break [mm]	Tensile strength R_m [MPa]
p-x1	1.42	2.56	699	25	245
p-x2	1.45	2.30	684	27	261
p-x3	1.44	2.32	754	29	288
p-x4	1.43	2.32	673	21	258
p-x5	1.52	2.45	736	27	252
Mean	-	-	**709**	**26**	**261**



a) b)

Fig. 11. Polymer bristle: a) during a tensile test, b) load-elongation curve

MICROHARDNESS

The microhardness measurements HV0,1 results are presented in Table 4.
The new wire has a similar microhardness at the level of 606 HV0.1 at various points. The microhardness at the end of the used wire has increased to 650 HV0.1 (mean value), but with the microhardness variation in the range of 625-700 HV0.1 (Table 4). The increase in microhardness at the end part of the wire can be related to the wire impacts on the hard pavement and dynamic deformation.

Table 4. The microhardness measurements HV0,1 results of new and used wires

	HV0,1					
	New wire		Used wire			
	599	580	700	639	632	654
	586	618	654	639	646	646
	592	612	661	632	632	625
	574	639	639	618	639	668
	639	632	632	700	646	668
	605	562	646	654		
Mean	**606**		**650**			
Std.	**24**		**21**			

5. Summary and conclusions

Foreign object debris (FOD) on pavements may be sucked in by jet engines and thus cause severe blade or propeller damage. There is also a risk that propeller or jet engine may cause the loose object to be “shot” like bullets against adjacent aircraft, vehicles or people. What's more, loose metal parts getting stuck in the tires pose a threat to the aircraft's wheels. Snow and ice removal from runways and taxiways allow avoiding frozen precipitation and slippery surfaces.

The use of various equipment is practicable in order to clean regularly all paved surfaces. Sweepers, integral sweeper-blowers, vacuum cleaners, a combination of snow plow and sweeper are available in different types, sizes and of different efficiency.

Parts from equipment for surface maintenance can also be a source of contamination. Brushes bristles made of steel or plastic are found on airport surfaces. Defects in fixing the bundles of polymer brush bristles during airport exploitation were found.

The tests carried out on the new and used brushes bristles have been presented. The tests included microscopic observations, microstructure assessment, tensile strength, and microhardness testing.

Research on steel wires has shown a partial loss of the zinc coating during the brush operation (potential corrosion), lowering the tensile strength and increase the hardness of the wires, which could lead to wires crack and break. The lack of zinc coating resulting from abrasion during the operation of maintenance equipment may indicate the improper method of applying this coating. The de-icing agents used at airports due to the high pH value of their solutions may also have contributed to the loss of the coating. The tensile strength of the used wire (2124 MPa, Table 1) is lower than the strength of the new wire by 11% and lower than the required (2240 MPa) in accordance with SAE ARP 5564.

Microscopic observations of polymer bristles indicate the presence of contaminants in the plastic material, which may come from the production process or foreign particles that have been pressed into the material during the operation of the equipment. The tensile strength of the plastic bristles (Table 3) is 261 MPa, while the required value according to SAE ARP 5564 is 33 MPa. Measurements of microhardness of new plastic bristles and after exploitation (different lifetime) could help in understanding the cause of about 8-fold exceeding the bristles' strength in relation to the required value.

The article confirmed the necessity of constant control parameters of new cleaning elements intended for airport maintenance equipment and condition of worn components, that can allow to evaluate the wear process of these elements and select appropriate products. It is vital that the cleaning elements for maintenance equipment are of proper quality to ensure that hazards do not develop such as excessive breaking brushes bristles due to poor properties of used materials and defects during manufacture. Therefore, the selected parameters of the cleaning elements should be controlled in the process of purchase and supplying airfields belonging to the Polish Armed Forces. This is an important issue in the aspect of the safety of air operations.

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