CLEANING OF ALUMINIUM SURFACE USING DIFFUSE COPLANAR SURFACE BARRIER DISCHARGE

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Introduction

Non-thermal plasmas have recently received increased attention because of their use in „clean technology“ industrial applications\textsuperscript{1}. The fact that these plasmas can be generated in large volumes and at atmospheric pressure makes them very attractive for various industrial applications\textsuperscript{1}–\textsuperscript{3}. However, if ambient air is used as the background gas, several serious difficulties are encountered in the plasma generation process. Amongst these are prohibitive power requirements, high gas temperatures, and disrupting instabilities. For the mentioned industrial applications the so-called „Diffuse coplanar surface barrier discharge“ (DSCBD), enabling to generate macroscopically homogeneous plasma in ambient air\textsuperscript{4,5} appears to be to be a very efficient solution. This novel type of discharge has already been successfully used for the treatment of the nonwoven fabrics, foils, wood, paper and glass\textsuperscript{6–9}.

Also in the industry producing metallic films and sheets the treatment of surfaces by non-equilibrium plasma could be solution for environmentally safe and low-cost in-line processing. For temporary corrosion protection or lubrication sheet metals are coated by organic oils. This coatings need to be removed in advance of further metal manufacturing processes. Usually, the cleaning is performed in wet alkaline or acid baths; however, these chemical treatments are problematic from environmental point of view. Therefore the non-equilibrium atmospheric-pressure plasma treatment seems to be a suitable alternative to the above-mentioned treatments\textsuperscript{10,11}. Another advantage of such a cleaning could be better performance concerning the activation of the treated surface what is useful for further coating of the surface. The aim of our experimental study was to investigate the possibility of the use of DCSBD discharge for the surface cleaning of aluminium and to evaluate the durability (ageing effect) of such a treatment.

Experimental apparatus and method

The simple scheme of experimental apparatus is shown in the figure 1. Surface modification was carried out using the Diffuse Coplanar Surface Barrier Discharge (DSCBD) generated in air at atmospheric pressure.

The DCSBD electrode geometry consists of 38 parallel stripline silver electrodes embedded 0.5 mm below the surface of 96% Al\textsubscript{2}O\textsubscript{3} ceramics (see Fig. 2). The discharge was powered by 14 kHz sinusoidal voltage, supplied by HV generator LIFETECH VF 700. The active plasma area has the dimensions 200 × 80 mm. The thickness of the plasma layer generated on the surface of the Al\textsubscript{2}O\textsubscript{3} ceramics is approximately 0.5 mm. The power supplied to the reactor was approximately 332 W. The 1 × 20 × 70 mm size samples were cut from 99.5% aluminium metal sheet. The samples were sonicated for 6 minutes in acetone prior to the plasma cleaning. By the treatment they were attached to a plastic cart. The cart was moving trough the discharge area at a constant speed carrying the sample. The distance between sample surface and the surface of the Al\textsubscript{2}O\textsubscript{3} ceramics was 0.3 mm. By changing the cart speed it is possible to change the treatment time.

In general, a good wettability of metal surface is considered a good indication that organic contamination was virtually absent from the cleaned surfaces. As a consequence, the following surface energy measurement was used as an indication of the plasma surface cleaning efficiency.

After the plasma cleaning the contact angle of one drop of distilled water (2 µl) on the treated surface was measured by the means of the Surface Energy Evaluation System (SEE System\textsuperscript{12}; Advex Instruments s. r. o., Czech republic). Supplied See Software 6.0 firmware was used to process the
droplet images and calculate the contact angle. Each resulting contact angle is an average of 20 measured values.

The ageing effect of the treatment was also studied. The contact angle measurement of the samples treated for a period of 3 s was done at several selected times (every hour in the interval from 0 to 8 hours and then at 24, 48 and 72 hours after the treatment). During the ageing study the samples were stored under ambient conditions. The results were compared to the untreated samples and to the treated samples stored in vacuum.

The possible changes in the morphology of the plasma-treated aluminium surfaces were investigated by the means of AFM microscopy using the Solver P47-PRO (NT-MDT Co., Russia) AFM setup. As a well defined aluminium surface the surface of Al-coated Si-wafers was used. The DCSBD plasma treatment was done in ambient air at the discharge power of 332 W. The treatment time was 3 s, the distance between the sample and the electrode surface was 0.3 mm during the treatment. By the means of AFM measurements the root mean square (RMS) roughness of the aluminium surfaces has been evaluated.

Experimental results and discussion

In the fig. 3a and 3b the shapes of water drops placed on untreated and plasma-treated sample, respectively, are shown. The discharge power was 332 W, the distance between sample and the surface of the dielectrics was 0.3 mm and the treatment time was 3 s.

In the fig. 4 the dependence of contact angle on the treatment time is shown. From the figure it is clear that after the treatment lasting for 1 s the contact angle changes dramatically. 3 s lasting treatment causes almost maximum wettability of the surface. The observed effect can be explained through the plasma induced removal of organic contamination from the treated aluminium surface11 with possible increase in surface –OH groups density, which are responsible for the wettable properties of oxide surfaces.

In fig. 5 the ageing effect of the 3 s treatment is shown. The contact angles on the sample stored in ambient air are compared to the contact angle of sample stored under vacuum and the contact angle of an untreated sample. From the figure it is clear that the wettability of the treated surface decreases with the storage time. This can be assigned to the adsorption of organic compounds from the surrounding ambient on the treated surface, which leads to the decrease in the free surface energy of the treated surface. This conclusion is supported by the result of the vacuum storage of the treated surface, where, due to the considerably lower content of the organic compounds in the surrounding ambient, the contact angle retained at lower value when compared with the surface stored in ambient air.

In the fig. 6 the AFM images of the untreated as well as the plasma-treated aluminium surfaces are shown. The comparison of the RMS values for the untreated and the plasma-treated aluminium surface revealed, that the 3 s lasting plasma treatment, which time is optimal to achieve the hydrophilisation of the surface, led to the slight increase in the roughness of the treated aluminium surface. The obtained value of the RMS roughness in the case of the untreated aluminium surface was 1.533 nm, whereas it’s value in the case of the plasma-treated aluminium surface was 1.866 nm.
Conclusions

Presented results of the plasma activation of aluminium surface demonstrate that the DCSBD plasma is an effective tool in enhancing the wettability (Fig. 4) of the treated surface. Treatment time of 3 s is sufficient enough to turn the treated aluminium surface hydrophilic. The observed effect was assigned to the removal of the organic contamination from the treated surface with possible increase in the surface hydroxyl groups density. The ageing effect of the treatment was observed, the wettability of the treated surface decreases with the storage time. This was assigned to the adsorption of the organic compounds from the surrounding ambient on the treated surface, which assumption was supported by the result of the vacuum storage experiment.

The AFM measurements showed slight increase in the surface roughness of the aluminium surface treated by the plasma at the treatment time of 3 s.

The preliminary results indicate that this novel atmospheric-pressure plasma source may be useful for the activation of the aluminium surface.