OPTIMIZATION OF THE PLASMA ELECTROSTATIC FILTER USING TAGUCHI METHOD

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We investigated the flow of carbon and metal vacuum arc plasma, produced in DC discharge with superimposed high-current arc pulses, through the electrostatic filter. The dependence of the filtering efficiency and the ion current of the plasma flow on the filter current, gas pressure, distance and tilt angle of the filter blinds was determined. The plan of the experiment was developed using Taguchi method and the conditions, which guarantee maximal cleaning efficiency at maximal plasma transmission through the filter were determined.
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1. INTRODUCTION

One of the drawbacks of the vacuum-arc method is the presence in the plasma flow, and hence in the condensate, a significant content of the microparticles. Progressive development of the vacuum-arc method has led to new methods of deposition, one of which is DC vacuum-arc method with superimposed high-current arc pulses. Over the past decades various designs of the plasma filter to remove droplet phase from the plasma flows have been developed. The most common design is a curved filter with crossed electric and magnetic fields, providing the most complete filtering of the plasma. The use of such a construction of the filter is not always possible because of the design features of the specific vacuum-arc device. In our case, for cleaning plasma from the microdroplets, we proposed the construction of an electrostatic filter.

Three versions of the linear Venetian blind filter [1] were manufactured and investigated. Distances between the lamellae and their tilt angles were selected in each version so that there was no line of sight between the cathode and the substrate. Another structural feature of the developed constructions is the possibility to change the position of the filters. Fixings of the filters are located on two perpendicular sides, what allows to install a filter either with vertical or horizontal position of the lamellae. Moreover it is possible to apply in the experiments 1 to 3 filters with combined positions of lamellae (zigzag, twisted, etc.).

2. EXPERIMENTAL TECHNIQUES

Experiments were performed on an industrial vacuum-arc device C55CT made by the German company INOVAP GmbH for the deposition of DLC coatings. The cathodes (70 mm in diameter) were made from pure titanium and pure carbon, arc currents of I_{Ti} = 100 A, and I_C = 50 A were applied, the duration of each deposition experiment was t = 5 min. Without changing structural features of the vacuum-arc device, instead of the arc source shield and its rotary mechanism a water-cooled rotary vacuum pass was installed, which holds the electrostatic filter (Fig. 1). Three prototype filters were produced in the form of a square frame of the size of 210 × 210 mm in which the lamellae were installed at three distances between them of: 10, 15 and 20 mm.

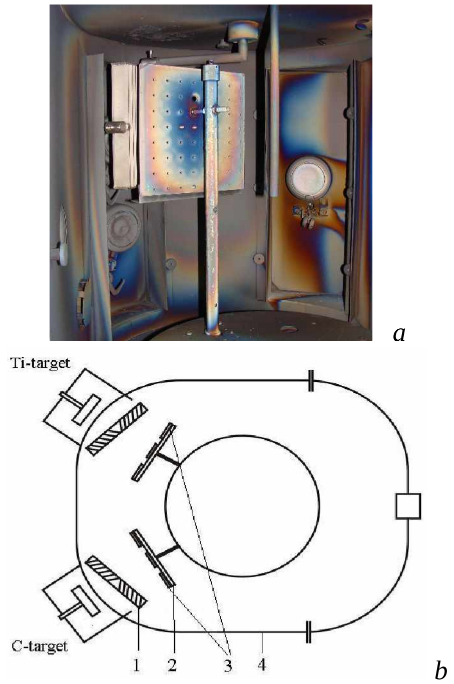

Fig. 1. Experimental setting in the C55CT device: a) view of the chamber interior, b) pictorial scheme; 1-electrostatic filter, 2-ion current collector, 3-investigated samples, 4-vacuum chamber

The lamellae were installed in each filter so that there was no line of sight through the filter between the cathode and the substrate. The filter was fed by a separate DC source. The ion current and the efficiency of the plasma flow cleaning from the droplet phase were measured using the ion current collector of the size of 210 × 210 mm (identical as the filter size). Three investigated samples for each experiment were installed in the central horizontal zone of the surface of the ion current collector. As the substrates silicon wafers for carbon and glass plates for titanium of the size of 20×20 mm were used. During the experiment, a negative potential of (-100) V was applied to the ion current collector, and the distance between the collector surface and the cathode surface was 200 mm.

The measurement of the ion current was carried out using CIE CA60 mA clamp-meter (OBIAT Pty Ltd Australia). In the current measuring range of up to 60 A

AC/DC clamp-meter allows one to connect to any multimeter. Number of microdroplets deposited on the substrates was measured using metallographic microscope ECLIPSE MA20 (Nikon Japan), the magnification of 500× was applied, and the area of microdroplets analysis was 22728 μm^2 for all samples. The Taguchi method of experiment design was applied [2], and the orthogonal tables L9 of the size: P = 4 (number of parameters), L = 3 (number of parameter values) were used for both titanium (Table 1) and carbon (Table 2). The experimental results were processed according to the Taguchi's procedure using the program "STATISTICA" (StatSoft Polska).

Table 1. Experimental parameters for Ti

№	Optimized parameter	Parameter values		
		1	2	3
1	Arc frequency f_{ARC} [Hz]	0	50	100
2	Argon pressure p_{Ar} [Pa]	0,001	0,4	1
3	Lamella distance L [mm]	10	15	20
4	Current of filter $I_{separ.}$ [A]	0	10	20

Table 2. Experimental parameters for C

№	Optimized parameter	Parameter values		
		1	2	3
1	Arc frequency f_{ARC} [Hz]	0	50	100
2	Argon pressure p_{Ar} [Pa]	0,01	0,1	1
3	Lamella distance L [mm]	10	15	20
4	Current of filter $I_{separ.}$ [A]	0	10	20

3. RESULTS AND DISCUSSION

The diagrams in Fig. 2 show the results of calculations of the dependence of the ion current on the process parameters for titanium cathode.

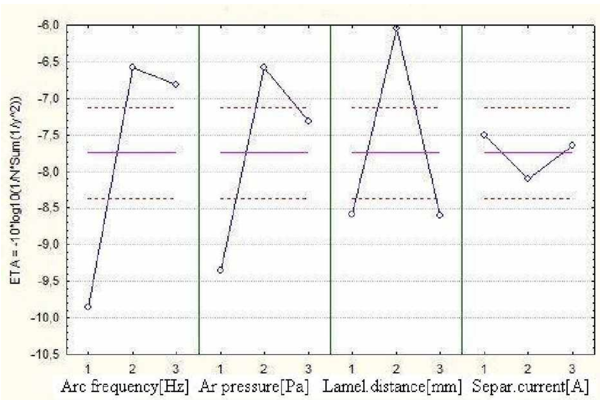

Fig. 2. Diagrams of the dependence of the ion current for titanium cathode on process parameters

The optimization criterion applied for the ion current was "the higher the better". As it is seen from the diagrams in order to obtain maximum ion current, the experiment should be carried out with the parameters: f_{ARC} = 50 Hz; p_{Ar} = 0,4 Pa; L = 15 mm; $I_{separ.}$ = 0 A (floating potential).

The diagrams in Fig. 3 show the results of calculations of the dependence of cleaning efficiency of titanium plasma from the microdroplets on the process parameters for titanium cathode. In the calculations as the measure of cleaning efficiency the ratio of the total surface of defects to the analyzed substrate surface (22728 μm^2) was applied, the optimization criterion applied was "the lower the better".

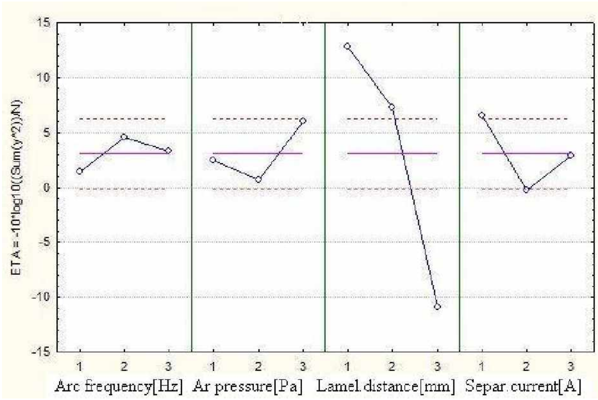

Fig. 3. Diagrams of the dependence of the cleaning efficiency of Ti plasma on the process parameters

Lamella distance is the main parameter determining cleaning efficiency and for maximum efficiency the experiment should be executed at: f_{ARC} = 50 Hz; p_{Ar} = 1 Pa; L = 10 mm, $I_{separ.}$ = 0 A (floating potential).

Similar calculations were carried out for results obtained for carbon cathodes (Fig. 4 and Fig. 5).

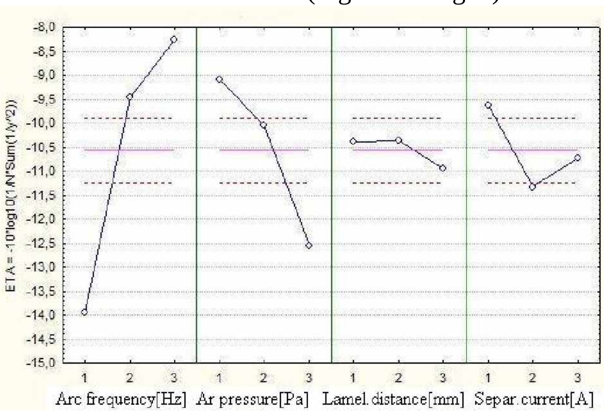

Fig. 4. Diagrams of the dependence of the ion current for carbon cathode on process parameters

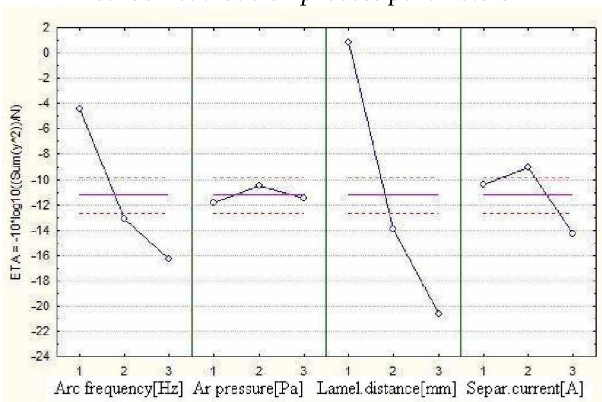

Fig. 5. Diagrams of the dependence of the cleaning efficiency of C plasma on the process parameters

The experimental parameters for maximization of the ion current are: f_{ARC} = 100 Hz, p_{Ar} = 0,01 Pa, L = 10 mm,

$I_{separ.}$ = 0 A (floating potential), and the maximum cleaning efficiency of carbon plasma should be achieved at: f_{ARC} = 0 Hz, p_{Ar} = 0,1 Pa, L = 10 mm, $I_{separ.}$ = 10 A.

The parameters determined using the Taguchi method, which maximize the ion current and the cleaning efficiency were verified experimentally. Besides, the experiments were made with the optimum parameters, which were selected taking into account the overall influence of each parameter on the ion current and the cleaning efficiency (Table 3 and 4).

Table 3. Maximizing and optimal parameters for Ti

Process	f_{ARC} [Hz]	p_{Ar} [Pa]	L [mm]	$I_{separ.}$ [A]	$I_{ion.}$ [A]	Droplets [%]
Max. I_{ion}	50	0.4	15	0	0,58	0,3
Max. cleaning	50	1	10	0	0,46	0,3
Optimal	50	1	15	0	0,55	0,2

Table 4. Maximizing and optimal parameters for C

Process	f_{ARC} [Hz]	p_{Ar} [Pa]	L [mm]	$I_{separ.}$ [A]	$I_{ion.}$ [A]	Droplets [%]
Max. I_{ion}	100	0.01	10	0	0,4	1,2
Max. cleaning	0	0,1	10	10	0,15	0,3
Optimal	50	0,01	10	0	0,28	0,3

Fig. 6 shows surfaces of the Ti and C films deposited without and with the electrostatic filter. Part of the microparticles are reflected from the lamellae and passes through the filter, within a certain distance and tilt angle of the filter blinds, but the obtained filtration efficiency is good enough for mechanical applications.

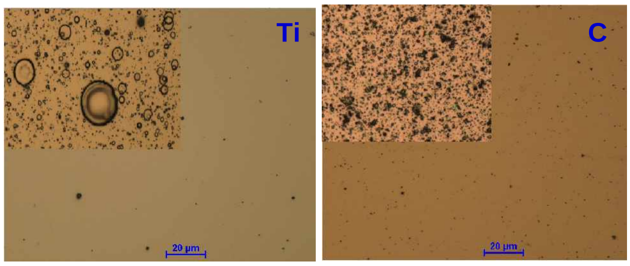

Fig. 6. Micrographs of the surfaces of Ti and C films deposited without (inserts) and with the electrostatic filter (magn. 500×)

4. CONCLUSIONS

The applied method of design of experiments – Taguchi method proved very effective for processing the experimental results and optimizing the parameters of the electrostatic filter. In the future, these findings will be very important and helpful in designing the final construction of the filter.

ACKNOWLEDGEMENTS

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REFERENCES

1. O. Zimmer. Vacuum arc deposition by using a Venetian blind particle filter// *Surface and Coatings Technology*. 2005, v. 200, p. 440-443.
2. M. Vijaya Babu, et al. Simultaneous optimization of flame spraying process parameters for high quality molybdenum coatings using Taguchi methods // *Surface and Coatings Technology*. 1996, v. 79, p. 276-288.

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ОПТИМИЗАЦИЯ РАБОТЫ ЭЛЕКТРОСТАТИЧЕСКОГО ФИЛЬТРА ПЛАЗМЫ С ИСПОЛЬЗОВАНИЕМ МЕТОДА ТАГУЧИ

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Исследовали прохождение углеродной и металлической вакуумно-дуговой плазмы, генерируемой источником постоянного тока с наложением сильноточных импульсов на ток дуги через электростатический фильтр. Были определены зависимости ионного тока и эффективность фильтрации плазменного потока от тока на фильтре, давления газа, расстояния и угла наклона жалюзей фильтра. План эксперимента был разработан с использованием метода Тагучи, и были определены условия, которые гарантируют максимальную эффективность очистки при максимальном коэффициенте пропускания плазмы через фильтр.

ОПТИМІЗАЦІЯ РОБОТИ ЕЛЕКТРОСТАТИЧНОГО ФІЛЬТРА ПЛАЗМИ З ВИКОРИСТАННЯМ МЕТОДА ТАГУЧІ

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Досліджували проходження вуглецевої та металевої вакуумно-дугової плазми, яка генерується джерелом постійного струму з накладанням сильнострумних імпульсів на струм дуги крізь електростатичний фільтр. Було визначено залежності іонного струму та ефективність фільтрації плазмового потоку від струму на фільтрі, тиску газу, відстані та кута нахилу жалюзій фільтру. План експерименту був розроблений з використанням метода Тагучі, та були визначені умови, які гарантують максимальну ефективність очищення при максимальному коефіцієнті пропускання плазми крізь фільтр.