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COMPOSITES THEORY AND PRACTICE

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EFFECT OF FLUIDIZATION TIME ON THICKNESS OF COMPOSITE PROTECTIVE-DECORATIVE COATING

This study examines how the fluidizing time influences the thickness and decorative properties of a protective coating created by the fluidization method. We have made two types of coatings: polyethylene and a composite (with polyethylene matrix and SiC particle reinforcement). The work, responding to the market demand for new attractive-looking materials, meeting certain preset criteria, such as coating thickness, is part of research into the selection of protective-decorative coatings for elements working in the natural environment, subject to UV radiation, wind and rain.

Keywords: ceramic-polymer composites, coating, fluidization method

WPŁYW CZASU FLUIDYZACJI NA GRUBOŚĆ KOMPOZYTOWEJ POWŁOKI OCHRONNO-DEKORACYJNEJ

W niniejszej pracy poddano badaniu powłokę dekoracyjno-ochronną wytworzoną metodą fluidyzacyjną w celu określenia wpływu czasu fluidyzacji na grubość tej powłoki oraz jej właściwości dekoracyjne. Wytworzono dwa rodzaje powłok: polietylenową i kompozytową (o osnowie z polietylenu i zbrojeniu z SiC w postaci cząstek). Praca ta stanowi odpowiedź na zapotrzebowanie rynku na nowe materiały o odpowiednim wyglądzie estetycznym, określonych właściwościach (w tym wypadku grubości) i jest częścią badań związanych z doborem powłok ochronno-dekoracyjnym na elementy pracujące w środowisku naturalnym narażonym na oddziaływanie promieni UV, wiatru i deszczu.

Słowa kluczowe: kompozyty ceramiczno-polimerowe, powłoka, metoda fluidyzacyjna

INTRODUCTION

The term *coating*, or *coat* was probably derived from anatomy, where it means an animal's external cover - the hair, wool, or fur, isolating the animal body from the environment. The term used in engineering disciplines replaced for good the occasionally-used term 'covering' [1].

Although the term was introduced in the 1950s, there is no general technological standard that would define the term coating and its types. The related standards, particularly those concerning corrosion [2] and corrosion protection [3, 4] take the concept of *coating* for granted and only define specific types of coatings.

Coatings can be classified by their purpose, thus we can distinguish protective, decorative, decorative-protective and industrial coatings [1, 5, 6].

Protective and protective-decorative coatings are used for safeguarding an item against harmful effects of the atmosphere and weather (oxidation, corrosion etc.), minor mechanical damage and for beautifying that item. A wide majority of non-metallic coatings has a protective-decorative function, particularly polymer, enamel and paint coats [1, 5, 6].

This work examines a decorative-protective coating made by the fluidization method. Tests were performed to determine the influence of fluidization time on the coating thickness and its decorative properties. Two types of coatings were created: polyethylene and a composite, the latter having a polyethylene matrix and an SiC particle reinforcement. The work has been initiated by market demand, among others, of the Szczecin-based MABO company, for new materials that satisfy specific decorative features and technical parameters, such as thickness. Besides, this study is part of research on the selection of protective-decorative coatings applied on elements, such as satellite TV dishes, working in the natural environment and subject to the impact of UV radiation, wind and rain.

FLUIDIZATION METHOD

The method utilizes the phenomenon where powders change into the fluid state, formed by a mixture of a powder and inert gas that in some respects resembles liquids. The transition to the fluid phase takes place when the inert gas flows through a bed from the bottom, provided that the rate of the gas flow is higher than a certain critical rate, which makes the bed change into the fluid state, and at the same time lower than the speed of gas stream that will raise particles of a given diameter. In the fluid state, we observe perfect mixing across the whole volume and very good heat exchange. The grain dimensions should be possibly identical and relatively small (50 to 250 μm), because smaller grains move into the fluid state at lower linear velocities of inert gas particles. The fluid bed forms when the gravity force of the material powder equals the push force *P* of the gas on its surface [5-9].

Forming a coating on a metal surface most often consists in immersing an object, properly prepared and heated to a require temperature, in a special chamber with a polymer powder suspended in an inert gas. The working temperature has to exceed the melting point of the applied material. The polymer in the form of super fine powder under the influence of gas whirls in the chamber and contacts the heated surface of the object, partly melts and sticks to it. After a practically established time, the object being fluidized becomes coated with a homogeneous film. When the object is placed in the fluid bed, the polymeric particles touching the hot object surface melt and create a coating adhesively bonded with the object material [5-9]. The process takes place in a fluidizer.

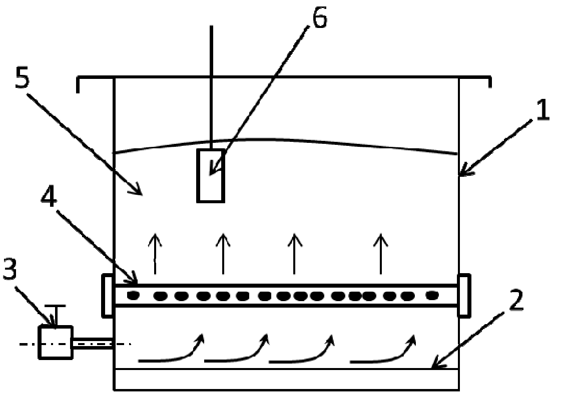

Fig. 1. Fluidizer construction: 1 - vessel, 2 - solid bottom, 3 - porous bottom, 4 - fluid bed, 5 - valve, 6 - object being fluidized [9]

Rys. 1. Schemat konstrukcji fluidyzatora: 1 - pojemnik, 2 - dno lite, 3 - zawór, 4 - dno porowate, 5 - złoże fluidalne, 6 - przedmiot, na który nanosi się tworzywo [9]

In order to obtain a uniform coating of good quality, the object removed from the fluidizer, depending on the type of material applied as the coating, may be again heated in a similar heating chamber or tunnel above the melting point of the fluidizing material [5, 6, 10].

Major factors that affect the process of fluidization include [5-9]:

a) object properties: its heating temperature, specific heat, thermal conductivity, density, shape and dimensions, condition of surface layer and surface proper
b) fluidizing material properties: melting point, specific heat, thermal conductivity, density, shape and size of particles
c) properties of porous bottom: shape and dimensions of pores, uniformity of pore distribution, condition of pore surfaces
d) gas properties: density, viscosity, flow rate, temperature, humidity
e) application method: time of keeping object in fluidized bed, i.e. time of fluidization, ambient temperature, movements of object in the bed.

The method is used to cover elements working or placed indoors, for example hangers, candle holders, tool grips. Satellite dishes are examples of fluidized objects for outdoor use.

MATERIAL FOR TESTS

The objects to be fluidized were plates of low carbon cold-rolled steel (S235) with the dimensions 35x12x2 mm. The coating material was a composite PE/SiC (Table 1), and for comparison, the matrix material: polyethylene (Table 1) in the fluidized form. The fluid bed for the composite coating was formed by adding 10% by weight silicon carbide (Fig. 2B) to polyethylene powder (Fig. 2A), both having particles of similar size.

a) b)

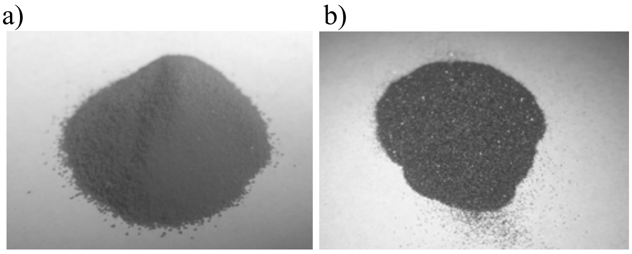

Fig. 2. Materials for coatings applied by fluidization method: a) polyethylene powder used for forming fluidized coating, also used as matrix, b) silicon carbide used as reinforcement for creating composite coating with PE matrix

Rys. 2. Materiały wykorzystywane przy wytwarzaniu powłoki metodą fluidyzacyjną: a) proszek polietylenowy wykorzystany do wytworzenia powłoki fluidyzacyjnej, stosowany również jako osnowa, b) węglik krzemu wykorzystany jako zbrojenie do wytworzenia powłoki kompozytowej o osnowie PE

TABLE 1. **Selected properties of polyethylene and silicon carbide [10, 11]**

TABELA 1. **Wybrane właściwości polietylenu i węglika krzemu [10, 11]**

Material	Grain size [μm]	Melting point [°C]	Density [g/cm^3]	Colour
Polyethylene powder	60	120÷125	0.94÷0.96	red
Silicon carbide (SiC)	50	2730	3÷3.15	graphite

The tests were carried out on the set-up shown in Figure 3. The fluidization process parameters were established experimentally.

a) b)

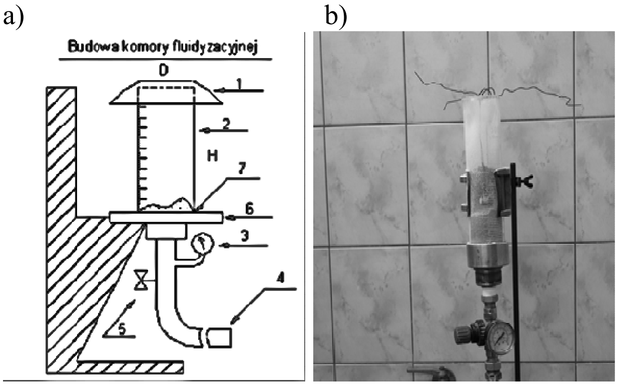

Fig. 3. Setup for applying fluidized coatings: a) schematic diagram: 1 - cylinder cover; 2 - glass cylinder; 3 - pressure gauge; 4 - compressed air supply hose; 5 - control valve; 6 - nozzle with strainer; 7 - polyethylene powder; D - cylinder diameter (66 mm), H - cylinder length (245 mm), b) photo of setup

Rys. 3. Stanowisko do wytwarzania powłok fluidyzacyjnych: a) schemat: 1 - nakrycie cylindra; 2 - cylinder szklany; 3 - manometr; 4 - wąż doprowadzający sprężone powietrze; 5 - zawór regulacyjny; 6 - dysza z sitkiem; 7 - sproszkowany polietylen; D - średnica cylindra (66 mm), H - długość cylindra (245 mm), b) widok rzeczywisty

Specimens for the tests were prepared by heating the substrate material to a temperature of 250°C in a lab furnace for a period of 300 seconds. Subsequently, each heated specimen was placed in a chamber where the fluid was in forced motion (Fig. 3). Five specimens were used for each of the various times of application: 30, 60, 90, 120, 150, 180 seconds. To improve the ornamental quality of the specimen surfaces, they were heated again to a temperature higher than the melting point of polyethylene.

Some fluidized coatings from the tests are shown in Figure 4.

a) b)

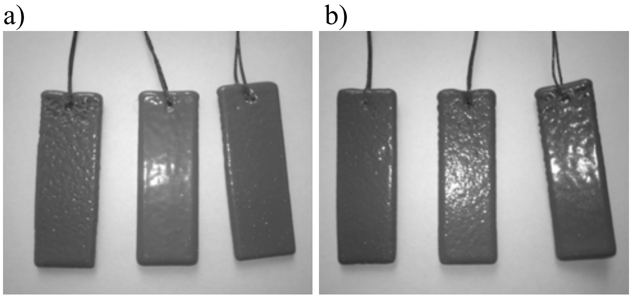

Fig. 4. Fluidized coatings of varying thickness: a) polyethylene coating, b) PE/SiC composite coating

Rys. 4. Przykładowe wytworzone powłoki fluidyzacyjne o różnej grubości: a) powłoka polietylenowa, b) powłoka kompozytowa PE/SiC

RESULTS AND ANALYSIS

This study aims at finding how the length of fluidization time affects the thickness of polyethylene and composite (PE/SiC) coatings as well as the decorative quality of the coating.

The coating thicknesses were measured by the contact method using an Elektro Physik Exacto FN gauge with a measurement range of 0÷2000 μm.

Six measurements were made for each specimen. Averaged values from the tests are given in Table 2 and Figure 5.

TABLE 2. **Averaged results of PE and PE/SiC coating thickness measurements**

TABELA 2. **Uśrednione wyniki pomiarów grubości powłok (PE i kompozytowej PE/SiC)**

Fluidization time	Coating thickness [mm]	
	PE coating	PE/SiC coating
30	0.472	0.737
60	0.605	0.954
90	0.885	1.205
120	1.221	1.356
150	1.418	1.439
180	1.711	1.72

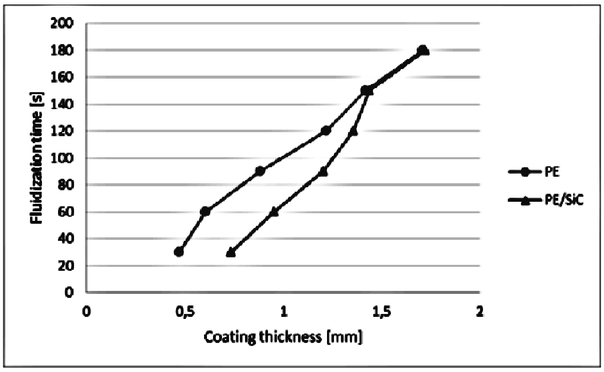

Fig. 5. PE and PE/SiC coating thickness depending on fluidization time (steel specimen placed in fluidizing chamber)

Rys. 5. Badanie grubości powłoki (PE i kompozytowej PE/SiC) w zależności od czasu przebywania próbki stalowej w komorze fluidyzacyjnej

It follows from the measurement results that as the fluidization time increases, so does the coating thickness, regardless of the coating material used (Fig. 5). In the case of the polyethylene coating, the relation is almost linear, until a critical thickness of about 1.71 mm is reached after three minutes. After the same period, the composite coating reached a similar thickness of 1.72 mm (Table 2). The convergent results may be due to substantial reduction of the specimen temperature, which inhibits melting and adhesion of another layer of fluid.

Too short a time of fluidization leads to porosity and visible holes in the surface (Fig. 6). In the composite coating, these defects occur more frequently than in the polyethylene coating, which is related to the presence of SiC particles that in contact with the hot substrate do not melt, thus hindering adhesion between the coating material and substrate. In the case of a critical 1.7 mm coating thickness, reduced adhesion of the coating is observed. This effect is visible for the composite material (Fig. 7) because stratification of the coating is due to the weight of the applied material, and the weight of the composite coating is higher due to the presence of silicon carbide.

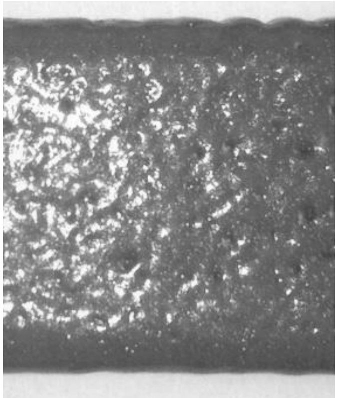

Fig. 6. Defects in composite coating after 30 s of fluidization

Rys. 6. Wady powłoki kompozytowej po 30 s fluidyzacji

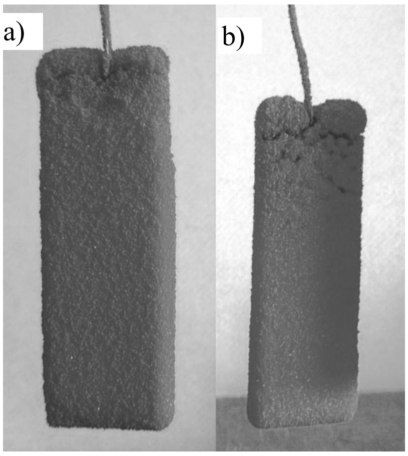

Fig. 7. Coating after 180 s of fluidization: a) polyethylene, b) composite

Rys. 7. Wygląd powłoki po 180 s fluidyzacji: a) polipropylenowej, b) kompozytowej

Comparing the relations between the fluidization time and coating thickness (Fig. 5) concerning both the composite material (PE/SiC) and pure PE we can notice that initially the increase in composite coating thickness is faster, which most probably is due to the presence of the additional material, SiC reinforcement, that has a high thermal conductivity.

When a certain fluidization time is exceeded, and correspondingly, the coating has a certain thickness, an additional operation has to be performed to even up the surface to improve its decorative quality. The operation consists in reheating the specimen to a temperature above the melting point of polyethylene, keeping it hot until the whole coating thickness becomes plastic, then it is cooled down. The thicker the coating is, the longer the heating time. For the materials used, the problem has been observed to occur in coatings more than one millimetre thick (Fig. 8).

The basic decorative criterion of a coating is its appearance, mostly assessed visually. The visual assessment takes into account such elements as colour, sheen, smoothness, as well as covering power. The addition of 10% by weight silicon carbide to the coating material leads to a worsened decorative quality of the coating in all respects (Fig. 9), which results from a darker colour and visible shapes of SiC (Fig. 2b) producing an effect of a slightly soiled coating.

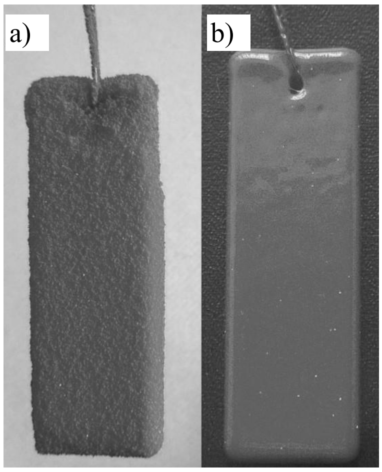

Fig. 8. Influence of heating after fluidization on surface quality: a) surface after fluidization, b) surface after fluidization and heating

Rys. 8. Wpływ wygrzewania po fluidyzacji na jakość powierzchni: a) po fluidyzacji, b) po fluidyzacji i wygrzewaniu

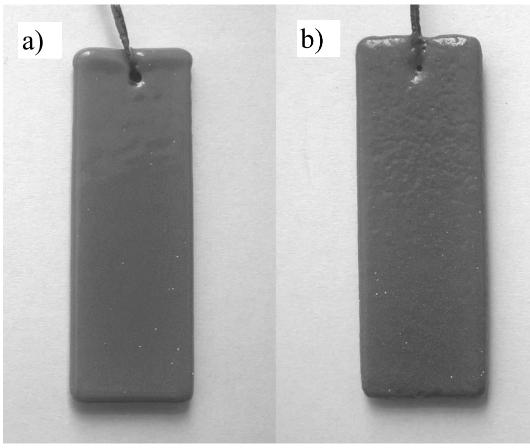

Fig. 9. Coating appearance after 120 s of fluidization: a) polyethylene, b) composite

Rys. 9. Wygląd powłoki po 120 s fluidyzacji: a) polipropylenowej, b) kompozytowej

CONCLUSIONS

The research discussed herein can be summarized with these observations:

- the presence of silicon carbide in a fluid hinders application of the coating, as SiC lengthens the time needed to achieve a tight coating, as compared to a coating of pure polyethylene
- polyethylene and composite coatings applied by the fluidization method on a metal substrate can be made to a specific thickness; excessive thickness leads to porosity caused by prolonged time of specimen presence in the fluidizing bath
- faster increment of composite coating thickness allows one to reduce the time of fluidization, and consequently, to enhance the protective properties of the coating.

Further analysis of material selection for protective-decorative coatings by the fluidization method requires abrasive wear and other tests that will be dealt with in future studies.

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