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Glassy coatings for solar energy conversion

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Glassy coatings have been shown to give very good corrosion protection to the steel substrate. Moreover they can also be utilised as a solar energy absorber. Introducing metallic particles into the glassy matrix can lead to coatings with improved mechanical strength and much higher thermal conductance of a resulting composite. Establishing of optimal conditions for synthesis of such coatings was the main goal of this work. The microstructure of the coatings was studied by SEM and optical microscopy while UV–VIS spectroscopy was used to estimate their optical properties.

Keywords: enamel, glass-metal composite, solar collectors.

1. Introduction

Combination of specific properties of enamels like chemical and mechanical durability, ability to absorb radiation in a wide range of spectrum (from UV to far infrared) with characteristic metal properties like high thermal conductivity, toughness and high strength can lead to interesting coating material. It can be applied as an absorber in some types of solar collectors [1–6]. Conventional enamels are characterised by low thermal conductivity typical for boro-silica glasses [7]. Thermal conductivity is additionally lowered by the presence of gas bubbles. Introducing metal components in significant quantity into the enamels leads to an increase in thermal conductivity. An additional effect relies on an increased absorption coefficient of coating.

The main goal of the work was to study the ability to introduce metallic powder into the enamel with two different compositions. Spectral properties, microstructure and adherence were also the subject of this study.

2. Materials and preparation

Alkaline boro-silica and non-alkaline glasses were used as a matrix. The first composition is characteristic of ground enamel, while the second one based on the system SiO_2–B_2O_3–PbO is often used for special coating preparation. The metals used as a filler are nickel and cobalt. They were introduced as a powder with grain diameter < 0.010 mm in the amount of 20 and 40 wt%. Firing of the coatings was conducted in an electric furnace in isothermal conditions. Firing parameters were selected experimentally, depending on the type of metal, amount, the type of matrix. The temperature was in the range of 600–800°C, while time of firing was constant in all cases. The coating material was prepared by mixing enamel powder with metal and ethanol. The suspension was applied on low carbon steel using an aerograph.

Microstructure of the coatings was studied by an optical and electron microscope:
– optical microscopy – Neophot 32 (observations were made on cross-section);
– electron microscopy Joel 5400 with EDS Oxford Instruments Link 300.

The assessment of enamel adherence to the steel substrate was conducted through observation of controlled deformation of the sample in Erchsene apparatus. Deformation diameter was 30 mm and the pepth of deformation amounted to 3.5 mm. The adherence was evaluated on the basis of The Institute of Vitreous Enamellers standards.

Spectral properties were measured in reflected light mode using a spectrometer Konica–Minolta CM-2600d with spherical geometry *d*/8.

3. Results and discussion

Conducted tests show considerable difference between cobalt and nickel behaviour during firing of the coating. Obtained glass-metal coatings had different microstructure, depending on the type of a filler. The cross-section of standard two-layer enamel is shown in Fig. 1, while the cross-section of enamel with metal particles is shown in Fig. 2. It is clear that the metal is equally distributed through the layer thickness.

Oxidation of metal powder and dissolution of resulted oxide leads to supersaturation and crystallisation of the glass. It substantially reduces fluidity of the enamel. In the case of studied materials, the required fluidity was achieved when the amount of nickel and cobalt does not exceed 40 wt%. Aggregations of metal grains are clearly seen in the SEM picture of a microstructure – Figs. 3 and 4. Dissolution of the metals

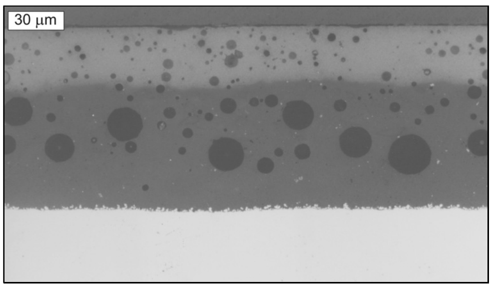

Fig. 1. Microstructure of conventional enamel.

and their oxides leads to spectral characteristic changes – Figs. 5 and 6. Despite higher reflectance, metal particles lead to higher absorbance, especially in a far infrared range. The process of cobalt dissolution in a glass matrix was studied by EDS and is

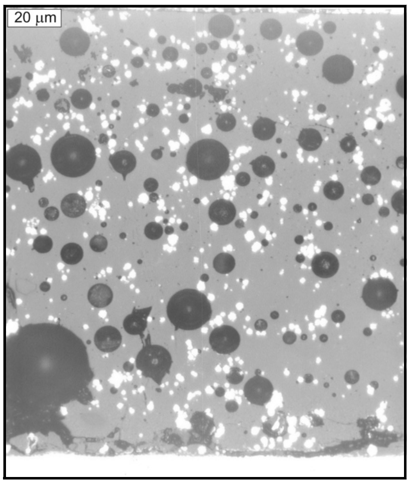

Fig. 2. Glass–metal composite with 40% of cobalt in alkaline matrix.

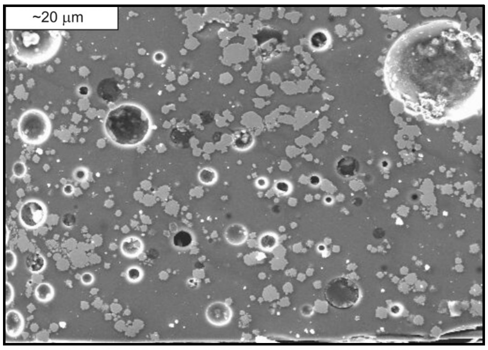

Fig. 3. Microstructure of coating materials comprising 60% of alkaline-free enamel and 40% of nickel.

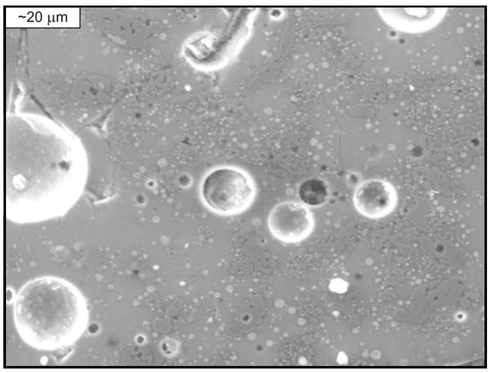

Fig. 4. Microstructure of coating materials comprising 60% of alkaline enamel and 40% of cobalt.

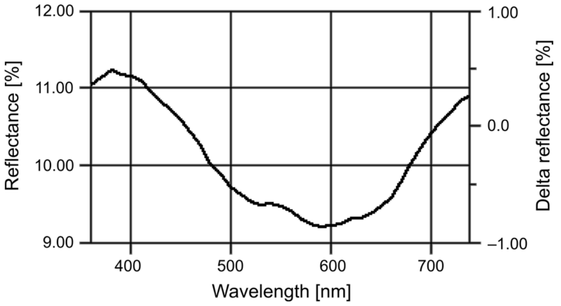

Fig. 5. Spectral characteristic of coating containing 20 wt% of cobalt in alkali-less glass.

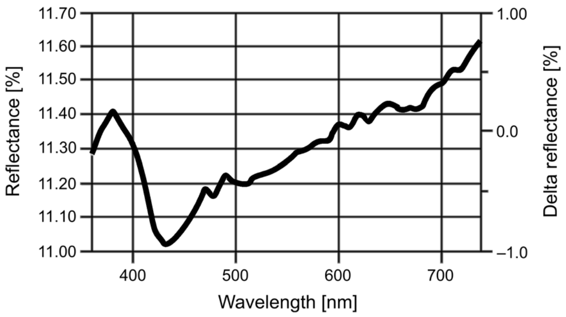

Fig. 6. Spectral characteristic of coating containing 20 wt% of nickel in alkali-less glass.

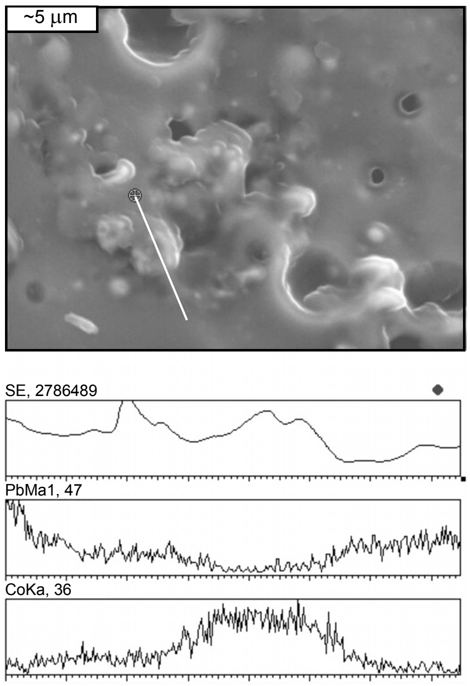

Fig. 7. Distribution of cobalt in cobalt crystallite region in glassy matrix.

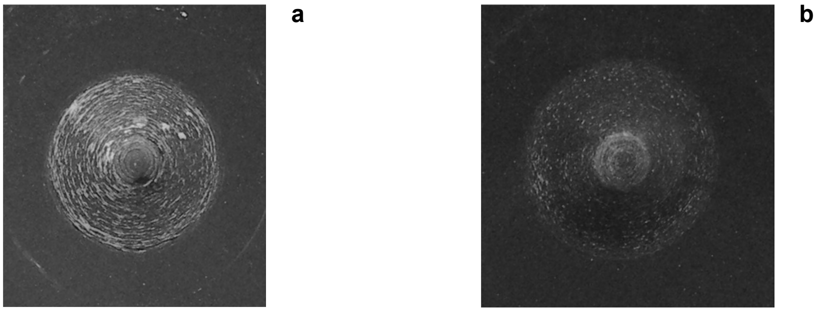

Fig. 8. Deformation zone after an adherence test in Erichsen apparatus. Conventional enamel (**a**), and enamel with metal particles (**b**).

shown in Fig. 7. Despite oxidation, the interior of the cobalt grain is still in a metallic form. Metal particles improved mechanical properties of the enamel, especially the adherence to the metal substrate. Figure 8 shows the picture of the samples after a deformation test in Erichsene apparatus in the case of standard enamel and enamel reinforced by metal particles. An improvement in adherence is clearly seen.

4. Conclusions

Conducted studies confirmed technological abilities to introduce cobalt and nickel metal particles on the level of 30–40 wt% into the alkaline and alkali-free glass -enamels. Metal particles improved mechanical properties, increased adherence and thermal conductivity of the coatings. Absorption in the infrared range was also improved. Glass-enamel coatings reinforced with metal particles can be applied as a absorber in medium and high temperature solar energy converters.

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