The Effect of Pulsed Electron-Ion Irradiation on Defects in Ceramic-Metal Coatings on Dies for Pelletizing Plastics

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Abstract. In the work, on the example of a coating of a metal-ceramic alloy of 50 vol.% TiC / 50 vol.% (Ni-Cr) of the working part of a die for granulating plastics, the results of the study of the possibilities of using the pulsed electron-ion irradiation method to eliminate continuity gaps in the coating in the form microcracks formed during operation of the die through through the cross section. It has been shown that pulsed electron-ion irradiation makes it possible to restore the integrity of metal-ceramic coatings by filling cracks with a melt of a nickel-chrome binder metal-ceramic composition extending to the surface of the coating of cracks to a depth of more than 100 μm.

Introduction

The final stage in the production of plastics at petrochemical plants is a granule formation process. For its implementation, devices consisting of an extruder, a die, and a cartridge with a set of blades are used to form plastic granules from the material extruded through calibrated holes in a ceramic-metal coating on the die surface. Some coatings include hard alloy bushings pressed into the steel die hull. Others are made in the form of a continuous set of trapezoidal plates from various ceramic-metal alloys (WC/Co, TiC/steel, TiC/Ni-Cr alloy) joined together. Fig. 1 shows a general view of the die coated with the TiC/Ni-Cr metal-ceramic alloy (each component of 50 vol. %) in the form of trapezoidal segments.

Fig. 1. General view of the die coated with the TiC/Ni-Cr metal-ceramic alloy and the blade for pelletizing plastics.
During operation, the TiC/Ni-Cr metal-ceramic coating on the die surface is subjected to repeated thermal cycling. This causes the initiation of microcracks on the inner hole surfaces. As a result, a mesh of micro- and macro-fractures is formed that contributes to the coating failure. The restoration of the die surfaces by replacing the plates is a laborious and expensive process. In this regard, it is urgent to develop a technology for restoring the integrity of the TiC/Ni-Cr metal-ceramic coating on the die surfaces by eliminating microcracks.

One of the possible ways for solving the problem is to modify the structure and the phase composition in the surface layer of the surface layers of metals and alloys by pulsed electron-ion irradiation [1–5]. This processing results in ultrafast heating and melting of the surface layer. Varying the modes of electron-ion irradiation is carried out by changing the electron-beam energy density, pulse duration and frequency, as well as a number of pulses.

The aim of this work was to study the effect of pulsed electron-ion irradiation in an inert gas plasma on the melting of the surface layer of the TiC/Ni-Cr metal-ceramic coating. This processing results in change in the size of microcracks and filling them with molten the nickel-chromium binder.

**Materials and methods**

Fig. 2 shows a segment of the TiC/Ni-Cr metal-ceramic coating on the die surface with microcracks indicated by arrows.

![Fig. 2](image-url)

**Fig. 2.** A segment of the TiC/Ni-Cr metal-ceramic coating on the die surface with a mesh of microcracks.

Through cracks adjacent to holes had been formed in the TiC/Ni-Cr metal-ceramic coating during the operation of the die. They were predominantly distributed between the individual holes and have various widths from 5 up to 100 µm. (Fig. 3).

![Fig. 3](image-url)

**Fig. 3.** Top view of cracks in the TiC/Ni-Cr metal-ceramic coating of the die.
Pulsed electron-ion irradiation of the TiC/Ni-Cr metal-ceramic alloy samples was done using a ‘SOLO’ vacuum facility [5, 6] in the argon plasma. Electron energy was 18 keV, pulse duration was 200 µs, the electron-beam energy density was 60 J/cm², and pulse frequency was 1 s⁻¹. The microstructure of the sample surface layers was investigated using a ‘Philips SEM-515’ scanning electron microscope (SEM).

Results and Discussion

A. Local electron-ion irradiation

Mode parameters (the electron-beam energy density of 60 J/cm², pulse duration of 200 µs, the number of pulses of 15, 30, and 50) for pulsed electron-ion irradiation of the die surfaces having through cracks (Fig. 4) were set based on the results of the previous studies [6-10].

Fig. 4. Segments of the TiC/Ni-Cr metal-ceramic coating used as the samples for irradiation (cracks are shown by arrows).

Fig. 5 shows the sample cross sections with cracks after pulsed electron-ion irradiation by 15, 30, and 50 pulses. During 15 irradiation pulses, the surface layer of the TiC/Ni-Cr metal-ceramic alloy sample had been melted, the carbide component had been partially dissolved, and the mouth of the cracks had been filled with the molten nickel-chromium binder. The process further filling cracks had been completed due to the insufficiently high level of heating of the deeper surface layers. In this case, the filling of the cracks was at a depth of about 0.1 mm (Fig. 5a). A more significant heating of the surface layer had been with a twofold increase in the number of pulses (Fig. 5b). After 30 pulses, the crack filling depth enhanced up to 0.7 mm. The depth of heating and subsequent crack filling had risen up to 1.2 mm with a further increase in the number of pulses up to 50 (Fig. 5c).
Fig. 5. Examples of filling the mouth of the cracks with the molten nickel-chromium binder as a result of pulsed electron-ion irradiation at the electron-beam energy density of 60 J/cm²: a – 15 pulses, b – 30 pulses, c – 50 pulses.

B. Pulsed electron-ion irradiation in the surface scan mode

At the next stage, the effect of pulsed electron-ion irradiation in the surface scan mode of the samples with dimensions comparable with the segment of the TiC/Ni-Cr metal-ceramic coating was studied. General view of the sample surface after irradiation in the scan mode is shown in Fig. 6. After irradiation, the sample was cut into specimens to study their cross sections at the crack locations.

Fig. 6. General view of the surface of the TiC/Ni-Cr metal-ceramic coating after pulsed electron-ion irradiation in the scan mode at the electron-beam energy density of 50 J/cm² and pulse frequency of 2 s⁻¹ (cracks are shown by arrows).

Fig. 7 shows examples of the specimen cross sections having cracks filled with the molten nickel-chromium binder upon pulsed electron-ion irradiation in the surface scan mode.
Fig. 7. Examples of cracks filled with the molten nickel-chromium binder after pulsed electron-ion irradiation of the surface of the TiC/Ni-Cr metal-ceramic coating: a – the through crack in the specimen cross section, b – the mouth of the crack, c – a part of the crack filled with the molten nickel-chromium binder next to the sintering defect.

SEM images of the specimen cross sections of the TiC/Ni-Cr metal-ceramic coating (Fig. 7) make it possible to conclude that pulsed electron-ion irradiation in the surface scan mode effectively filled both the mouth of the cracks at the specimen surfaces and the whole cracks to a sufficiently large depth (more than 1 mm) with the melted nickel-chromium binder.

Conclusions

Pulsed electron-ion irradiation is an effective method for through crack elimination in the TiC/Ni-Cr ceramic-metal coating on the dies for pelletizing plastics. Irradiation conditions ensure the melting of the nickel-chromium binder in the surface layer and its filling in the mouth of cracks to a depth of more than 100 μm. Pulsed electron-ion irradiation in the surface scan mode makes it possible to restore the TiC/Ni-Cr ceramic-metal coating of used cracked dies in industrial conditions.

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