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Laser-based process for polymeric coatings on temperature-sensitive metallic components

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Abstract

Multiple applications, especially in the automotive sector and in mechanical engineering, are predominantly affected by friction and wear stress and, therefore, represent a substantial challenge for the components being used. Oftentimes, the endurance and the efficiency of these components can be enhanced by means of application-specific coatings. For multiple applications, the functional requirements can be met sufficiently by polymeric coatings. Particularly, coatings based on high performance thermoplastic polymers like Polyetheretherketone (PEEK) have an outstanding potential due to their excellent properties in terms of temperature resistance and wear protection.

Conventionally, PEEK is deposited in powder form and, subsequently, workpiece and powder are heated above the melting temperature of PEEK (approx. 340°C) by oven. Accordingly, this process is not suitable for temperature-sensitive base materials which show undesirable thermally induced effects (e.g. decrease of hardness) for temperatures below 340°C. A promising approach to enlarge the range of processable materials consists in the investigation of a laser-based process. Due to melting the PEEK with temporally and spatially controllable laser radiation, the thermal load of the workpiece is reduced. This process comprises four consecutive steps: a laser-based pre-treatment of the components, the preparation of a hydrous dispersion based on PEEK powder, the deposition of the dispersion by e.g. spray coating, and the laser-based melting of the PEEK powder.

Regarding the pre-treatment using pulsed laser radiation, current investigations primarily focus on the dependence between the induced roughness and the adherence of the coating. For the laser melting process, the main goal is identifying a process window for dense and adherent coatings without thermally induced effects on the base material. By means of this new coating process, dense and adherent coatings with a thickness of 15 – 45 µm can be applied on steel substrates. The adherence is significantly increased by the laser-based pre-treatment of the metallic substrates.

Keywords: Surface Functionalization; Fundamentals and Process Simulation

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1. Motivation

High-temperature resistant thermoplastics like Polyether Ether Ketone (PEEK) are well suited for applications affected by friction and wear stress due to outstanding temperature resistance, a low coefficient of friction, self-lubricating properties and an extensive chemical resistance [1]. Hence, PEEK is an excellent material for tribological coatings, especially for metallic components. Conventionally, the coating is applied in a two-step process. Firstly, the PEEK powder is deposited onto the component by means of spray coating. Subsequently, the entire component is heated above the melting temperature of PEEK (approximately 340 °C [2]) in an oven. Typical holding times range from a few ten minutes to several hours. Consequently, the process is not suited for temperature-sensitive base materials that show thermally induced changes of the microstructure (e.g. reduction of hardness) as a result of the corresponding thermal load [3].

A promising approach to reduce this thermal load and to prevent these changes consists in melting the PEEK powder with laser radiation [4]. Since the energy deposition is temporally and spatially controllable, the thermal load and the energy consumption can be reduced. The investigated process chain comprises four consecutive steps (Fig. 1): the laser-based pre-treatment of the substrates (1), the preparation of a hydrous dispersion based on PEEK powder or preparation of powder blend (2), the deposition of the dispersion by knife coating or the deposition of the powder blend by spray coating (3), and the laser-based thermal post-treatment by means of melting the PEEK powder with IR-laser radiation (4) - referred to as laser melting.

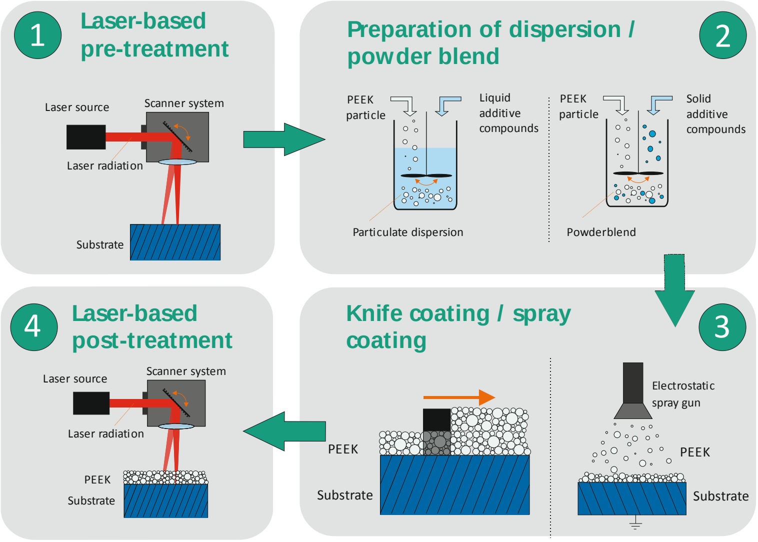

Fig. 1. Schematic diagram of the laser-based process chain

The presented research is primary focused on validating the feasibility of the presented process chain, particularly with regards to the laser-based pre-treatment and the laser melting. Accordingly, the influence of the laser-based pre-treatment on the adhesion and the influence of the parameters during laser melting on the adhesion and density of the coating are investigated.

2. Material and method

The experimental setup for the two laser-based process steps is shown in Fig 2 (*left*). The main components are a scanning unit and an f-theta lens. The laser sources are correlated to the scanning units via an optical fiber and a collimation optic. The laser beam is deflected by the scanning in a meander-shaped scanning path according to Fig 2 (*right*). For the pre-treatment, pulsed laser radiation (λ = 1064 nm) with a pulse duration $t_p < 50$ ns and a beam diameter $d_S < 50$ µm is used. For the laser melting, a laser system in continuous-wave mode (cw, λ = 980 nm) with a beam diameter $d_S > 2$ mm is used. The according scanning velocities are $v_{sc} = 1000$ mm/s and $v_{sc} < 100$ mm/s respectively.

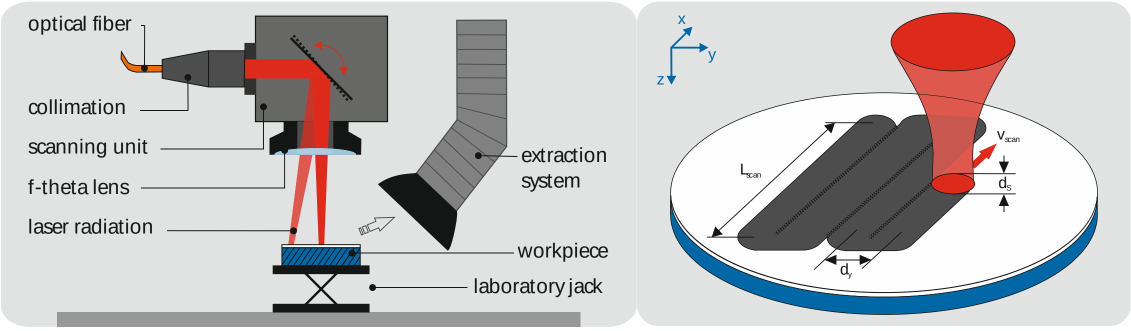

Fig. 2. left - experimental setup
right - Schematic image of the meander-shaped scanning paths
(line length L_{scan}, hatch distance d_y, scanning velocity v_{scan} and beam diameter d_S)

In order to investigate the influence of the laser-based pre-treatment on the adhesion of the coating, firstly, cylindrical substrates made of 100Cr6 (1.3505) with a height of 4 mm and a diameter of 31 mm were pre-treated with systematically variating process parameters. Subsequently, a PEEK-based dispersion was deposited onto these substrates by means of knife coating. The dispersion was composed of commercially not available PEEK powder with an average particle size of $d_{50} \approx 7$ µm and Isopropanol. Afterwards, the PEEK layers were melted with laser radiation. The resulting PEEK coatings were then evaluated by cross-cutting tests and scanning electron microscopy (SEM) regarding their adhesion.

For investigating the influence of the parameters during laser melting on the adhesion and relative density of the coating, the parameters during pre-treatment were fixed and the parameters during laser melting were varied systematically.

3. Results

Fig 3 shows SEM images of PEEK coatings after laser melting without and with laser-based pre-treatment. Without pre-treatment, the PEEK layer is completely delaminated and shows no adhesion to the substrate. With pre-treatment, PEEK layer and substrate show a form-fitting connection which is an indicator for excellent adhesion. According to the cross-cutting tests, an optimal adhesion as achieved with a surface roughness after pre-treatment of Ra ≈ 1.2 µm (s. Fig. 4). In comparison, the initial roughness of the substrates was Ra = 0.2 µm. Hence, the adhesion between coating and substrate is promoted significantly by the pre-treatment with pulsed laser radiation and the induced roughening effects. A qualitatively equivalent behavior was found in [5] and [6] during investigations with regards to the adherence of flame sprayed PEEK coatings on substrates made of Steel and Aluminum respectively.

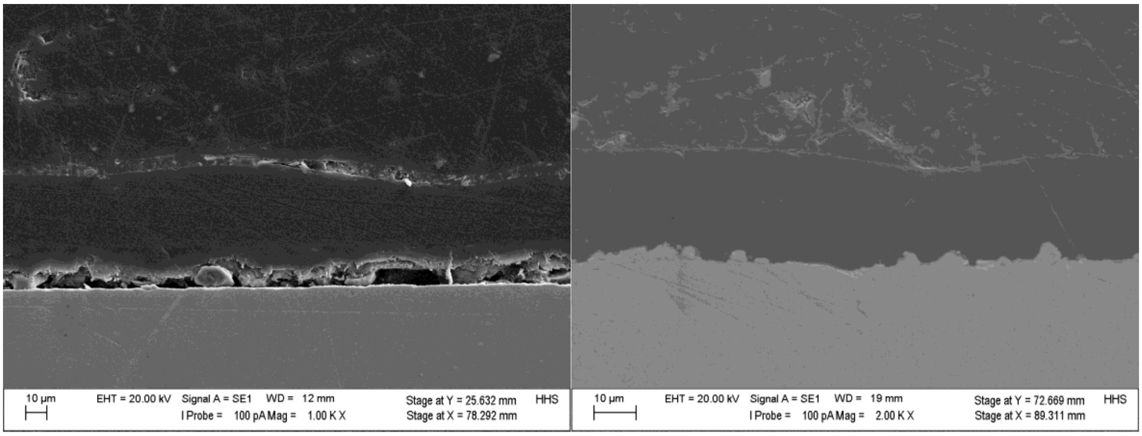

Fig 3: SEM image of PEEK coating after laser melting without (*left*) and with (*right*) laser-based pre-treatment

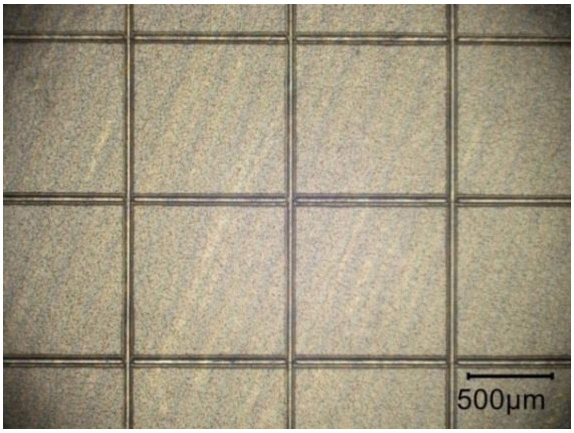

Fig 4: microscopic image of a coating after cross-cutting test
(surface roughness after pre-treatment Ra ≈ 1.2 µm)

Fig 5 shows microscopic images of coatings after laser melting with different preheating temperatures. The density of the coating increases with this temperature. For T = 300 °C, the coatings show no defects which indicates a relative density of nearly 100%. A possible explanation of this behavior is the resulting time span of the molten state. For temperatures of T = 25 °C and T = 170 °C, the PEEK layer instantly solidifies when reaching the melting temperature due to a self-quenching mechanisms. This mechanism is induced by the significant temperature difference between PEEK and substrate. For T = 300 °C, the temperature difference is sufficiently small to prevent an instant solidification and the time span of the molten state increases. Hence, PEEK layer can consolidate into a dense coating.

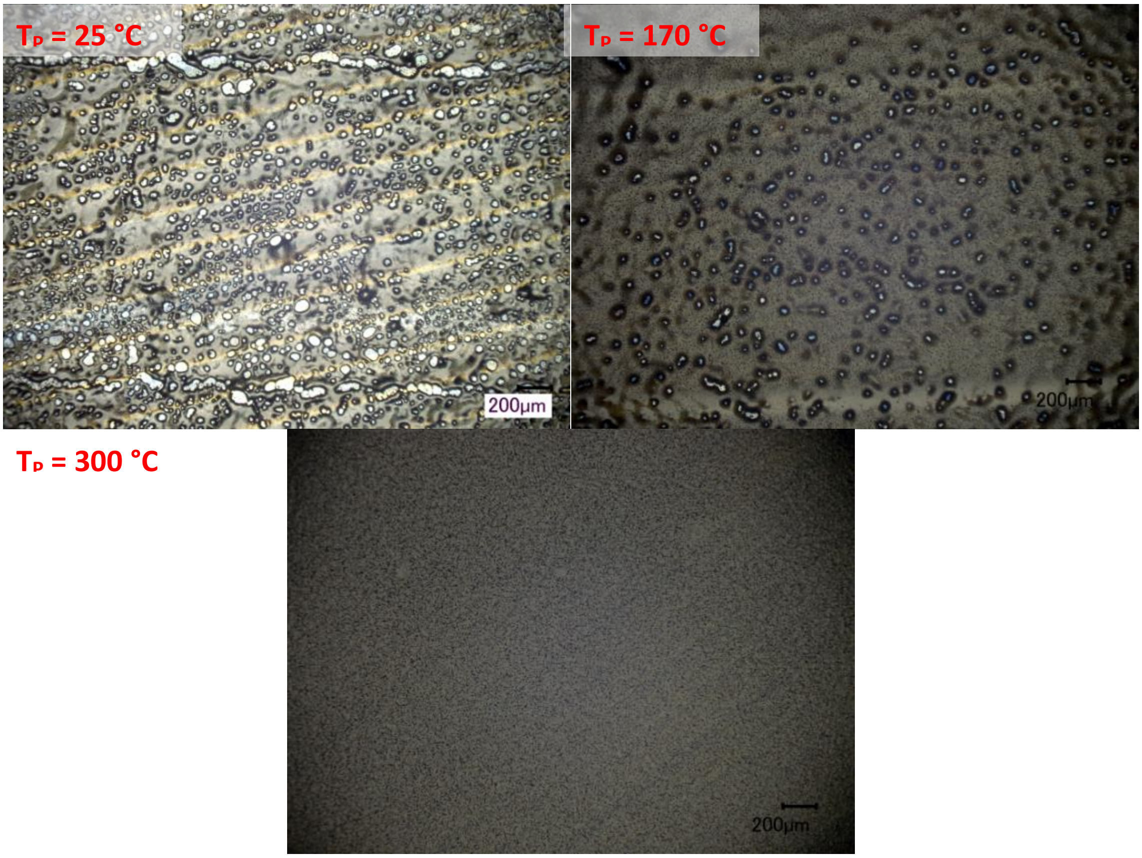

Fig 5: microscopic image of a coating after laser melting with different preheating temperatures

4. Conclusion and Outlook

An innovative laser-based process for polymeric coatings on temperature-sensitive metallic components was presented and the feasibility of the process chain was validated. Additionally, the investigations showed that a pre-treatment with pulsed laser radiation significantly promotes the adhesion between coating and substrate. By means of laser melting, dense and adherent PEEK coatings can be produced. The density is mainly influenced by the time span of the molten state. In case this time span exceeds a critical value, the layer consolidates into a dense coating.

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