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PULL-OFF STRENGTH AND IMPACT RESISTANCE OF POLYUREA COATINGS IN HYBRID COMPOSITES

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Abstract: *The main purpose of the presented paper is to determine the pull-off adhesion of polyurea coatings on the basis of polymer laminates. For this purpose, three types of laminates were prepared on a polypropylene matrix, a styrene-butadiene-styrene copolymer and an epoxy resin. The laminates were coated with a polyurea resin. The coating was applied with a special hot spray device, because of the strongly reactive precursors. The pull off strength needed to destroy the examined joints was compared and the macroscopic analysis of damage caused by the hit impactor with the energy of 19.6 J was performed. Impact damage and the structure of layered composites were subjected to microscopic analysis.*

Keywords: laminates, polymer composites, coatings, pull-off strength

1. Introduction

Polymeric coatings are mainly used as coatings for metal surfaces and their role is primarily to protect the basis against corrosion (Baek et al., 2009). In addition to metal surfaces, polymer coatings are also applied to other surfaces, such as concrete, wood and plastics (Awaia et al., 2009 and Dmitruk et al., 2017). These coatings allow to provide the desired decorative properties and specific mechanical properties, i.e. anti-friction. In the recent years, polyurea, polyurethane and polyurethane-polyurea resins have become increasingly popular among film-forming polymers (Mayer et al., 2012). These materials are resistant to mechanical wear in the form of abrasion, tears and scratches. Due to their specific properties, they are used as covers for tanks, cargo surfaces of vehicles as well as concrete surfaces, where they are used as waterproofing layers. In addition, these materials can be used as sound and vibration isolation.

The presented work uses polyurea coatings for covering of polymer laminates reinforced with aramid fabric. These types of laminates are used as ballistic shields or constitute one of the layer of a composite sandwich shells. The polyurea coating, due to its specific properties, can become one of the layers of a composite ballistic shield. The aim of the research undertaken in this work is to investigate the pull-off adhesion and impact resistance of polyurea coatings on the basis of polymer laminates.

2. Methods

The paper presents a method of producing of polymer laminates with elastomeric polyurea coating. The laminates were made on three polymer matrixes. The following polymers were applied as the matrix of the laminates tested in the work: (1) the epoxy resin (EP) trade name LH 289, manufactured by Havel Composites, (2) the polypropylene (PP) Moplen HP548R produced by LyondellBasell and (3) styrene-butadiene-styrene (SBS) copolymer, KRATON® D0243 provided by Kraton Polymers Company. To

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reinforce the tested laminates Twaron® aramid fabric of basic weight of 173 g/m^2 and plain weave, supplied by Havel Composites, was used.

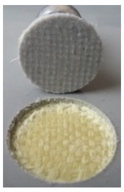
The matrix used for the first series of laminates was a two-component epoxy resin (EP). As a resin hardener, a product of the same company with a designation of H 136 was used. Epoxy laminates were laminated manually. The polypropylene and styrene-butadiene-styrene laminates were formed in two stages. The first step was the formation of the polymer film from granulate which initially was plasticized under a press at the temperature of 200 °C (for PP) and 180 °C (for SBS) for 2 min without load, and then for 2 min under the pressure of 2 MPa. As a result of pressing polymer films were obtained. The laminates were produced by the alternate pressing of 11 layers of polymer film and 10 layers of aramid fabric arranged in a metal mold. They were pressed under the pressure of 5 MPa.

As a coating for the prepared laminates, an elastomeric, polyurea resin (PUA) (MasterSeal M 689®) was used. Its precursors are strongly reactive and therefore the coating should be applied only with a special hot spray device for two-component products. The elastomeric polyurea coating was formed during the reaction of the isocyanate component (A) with resins containing amino groups (B). A high-pressure aggregate was used to apply the coating, the head of which made it possible to heat the ingredients from 20 °C to 75 °C (phase A) and 66 °C (phase B), and then to mix them. The material was sprayed at a pressure of 150 bar, at a distance of about 20 cm from the fabric surface. PUA resin was provided and was sprayed by ELIN Company from Wrocław. The coating thickness was about 1 mm.

2.1. Pull-off adhesion test

The main aim of this work was to determine the pull-off adhesion and impact resistance of obtained coatings and laminates. Properties of manufactured laminates with PUA coatings are summarized in Table 1.

Tab. 1: Characteristics of the manufactured laminates with PUA coating.

Designation of samples	**The polymer matrix of laminates**	**Macroskopic analysis (dolly face and coated surface)**	**Pull-off strength [MPa]**	**The nature of the fracture**
A	Polypropylene (PP)		0	Adhesive fracture between PUA coating and PP matrix of laminate
B	(Styrene-butadiene-styrene) copolymer (SBS)		1.5 ± 0.1	Adhesive fracture between SBS matrix and aramid fabric
C	Epoxy resin (EP)		5.1 ± 0.9	Cohesive fracture within EP matrix of laminate

The pull-off adhesion of the polyurea coating on different polymer substrates was carried out according to the (PN-EN ISO 4624:2004) standards by Posi Test AT. The Posi Test AT Pull-Off Adhesion Tester allows to evaluate the adhesion (pull-off strength) of a coating by determining the greatest tensile pull-off that it can bear before detaching. Breaking points, demonstrated by fractured surfaces, occur along the weakest plane within the system consisting of a dolly, glue, coating layers and substrate. Upon completion of the pull-off test, the dolly and coated surface was examined. In Fig.1 the nature of the facture is shown.

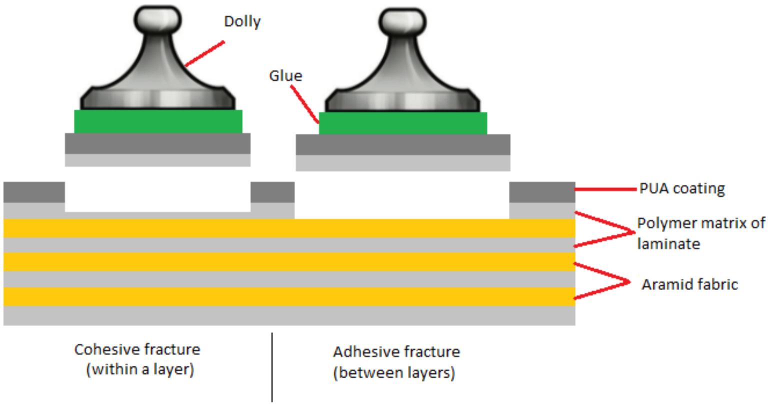


Fig.1: Damage diagram between the polyurea coating and the polymer laminate substrate.

2.2. Impact resistance method

Impact resistance tests were carried out in accordance with (PN-EN ISO 6272-1: 2011) standard. The method consists in determining the minimum height from which the 20 mm diameter impactor falls, causing mechanical damage to the coating. The test consisted in impact with a 2 kg impactor from a height of 1 m, obtaining energy of 19.6 J. After one impact, the PUA coating on the EP laminate was damaged (Fig. 2). On the opposite side to the place where the stress was applied, no macroscopic damage was observed. On other SBS and PP laminates with PUA coating, neither coating nor laminate damage was observed.

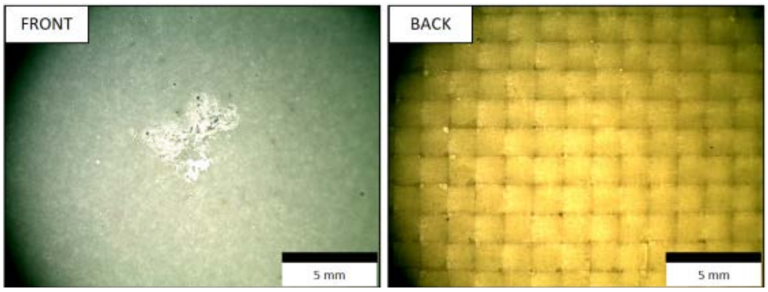


Fig.2: Optical microscope images of damage on the polyurea coating surface and back of epoxy laminate substrate (C samples) after 1 impact, 7x magnification.

In the next stage, samples were repeatedly impacted in the same place until mechanical destruction. Damage of the samples obtained in the impact resistance test is summarized in Fig. 3.

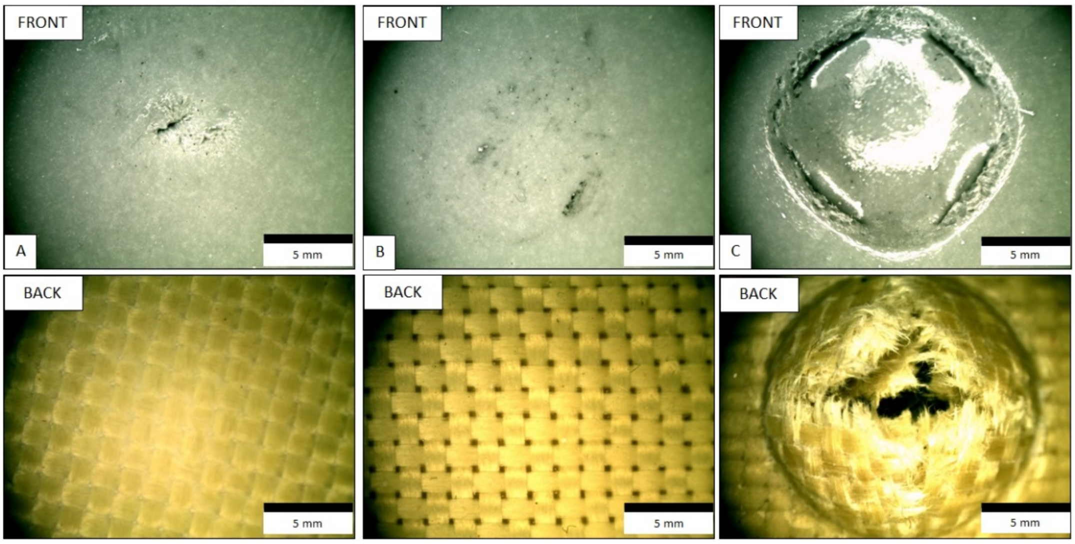


Fig. 3: Optical microscope images of damage on the polyurea coating surface and back of laminates substrate with polymer matrix: A - polypropylene (10 impact), B - styrene-butadiene-styrene copolymer (10 impact), C - epoxy resin (5 impact), (7x magnification).

2.3 2.3. The Scanning Electron Microscopy (SEM) analysis

Hybrid composites morphology of the laminates was examined with a scanning electron microscope (SEM) model JEOL JSM-6610A. Selected samples were included in epoxy resin (Epofix Resin). The results of the SEM analysis are shown in Figure 4.

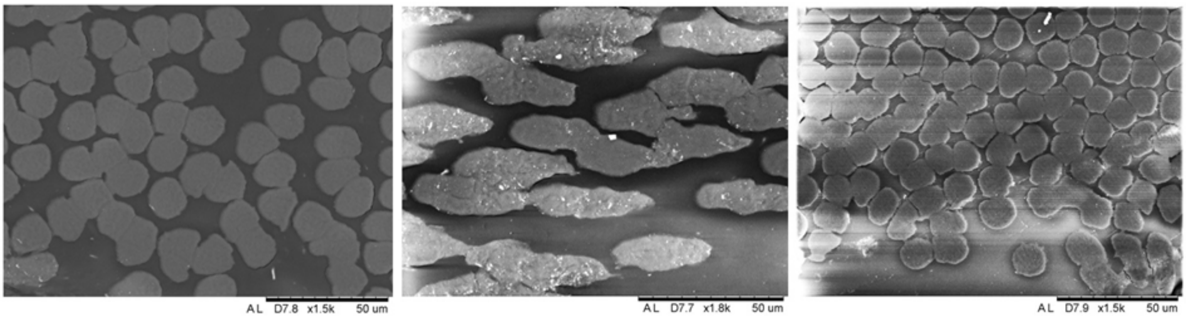


Fig. 4 Exemplary sample's cross sections of hybrid composites consist of PUA coating and laminates with polymer matrix: A - polypropylene, B - styrene-butadiene-styrene copolymer, C - epoxy resin.

The fiber bands of the aramid fabric as well as individual fibers in the band were saturated with both the EP, PP and SBS matrix. This demonstrates the correct preparation of laminates. Laminates differ in the interaction of the interface with the PUA coating. There is no interaction with the laminate on the PP matrix.

3. Conclusions

The following conclusions can be expressed on the basis of the research:

Among the polymer connections tested with the PUA coating, the highest value of the force required to break the joint was recorded for the epoxy resin. In these joints, cohesive fracture within EP matrix of laminate was observed. An adhesive fracture between SBS matrix and aramid fabric was observed for SBS laminates, however the values of the recorded force were much smaller.

For PP laminates, the adhesion of the polyurea coating was negligible. The coating was combined with the laminate on the polypropylene matrix only due to the mechanical connection and contraction of the polyurethane at the edges of the laminate. In this type of connections it is necessary to use an intermediate layer, i.e. epoxy, or to activate the polypropylene surface.

Impact resistance of the PUA coating and the type of damage depend on the type of substrate. For the PUA coating on the EP laminate, after one impact, damage of the coating and brittle cracking of the epoxy resin were observed. After five strokes, both the coating and the substrate of the EP laminate were damaged. For the PUA coating on PP and SBS laminates, no damage was observed after one impact. After 10 strokes, neither the laminate on the SBS matrix nor the PUA coating were damaged. In the case of composites consisting of a PP laminate and a PUA coating, the coating and laminate were damaged after 10 strokes. There are visible white areas on the underside of the laminate which indicates the delamination of the matrix.

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