Tribology International 43 (2010) 1175–1179

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Welding of tribologically optimized polyetheretherketone films with metallic substrates

T. Bayerl [a], A.K. Schlarb [b,*]

[a] Institut für Verbundwerkstoffe (IVW) GmbH, Erwin-Schrödinger-Str., Geb. 58, 67663 Kaiserslautern, Germany
[b] Chair of Composite Engineering (cCe) and Research Center OPTIMAS, University of Kaiserslautern, Bld. 44, 67653 Kaiserslautern, Germany

ARTICLE INFO

Available online 21 December 2009

Keywords:
Hybrid bearing
Shear strength
Wear resistant coating
Sliding contact

ABSTRACT

A thermal impact welding process has been developed which allows the thermal joining of polyetheretherketone (PEEK) matrix materials with steel and aluminum substrates, respectively. The objective is to render manufacturing of innovative slide elements possible without the need for an up to now commonly used layer of sintered bronze in order to enhance the adhesion of the polymer. It is proven that excellent joining quality and wear resistance of the polymer layer can be achieved without sintered bronze.

1. Introduction

Metal/fiber reinforced plastic composite bearings consisting of a metallic basis and a polymer tribo coating are produced up to now by extrusion of the polymer on the metal and subsequent hot plate welding or rolling [1,2]. In the case of the hot plate welding, the tribologically optimized polymer is pressed after the extrusion by a heated tool on the metallic substrate. The components are firmly joined after solidification under pressure. One of the challenges to face, while working with this process, is the prevention of adherences on the hot-tool which degrade thermally and can cause an integrity reduction of the tribo layer when introduced in the welding zone [3,4]. The idea to use a PTFE-coated hot-tool does not completely prevent this problem and is furthermore not suitable for polymers with melting temperatures over 260 °C [4,5]. A smooth tribo coating can only be achieved by the exact control of temperature and pressure during the process since e.g. a pressureless solidification of the polymer leads to shrinkage and so to less joining quality and to an uneven wear surface. The challenges of the complex hot-tool process have been previously described in detail [3–10]. In the case of uneven surfaces after welding, a mechanical finishing is inevitable for the use as bearing coatings.

To assure a high joint quality between polymer and substrate, the metallic basis is previously coated with a porous layer of sintered bronze which has the function of improving the adhesion by interlocking [2,11–13]. Nevertheless, regarding the manufacturing and operational safety, the sintered bronze layer is a challenging and high priced component in the slide element setup. The silver bullet for improving sintered bronze containing slide bearings would be to omit the sintered bronze but achieve the same joining and tribological quality. Furthermore, the process should provide a smooth tribo-surface of the coating after application on the substrate without further finishing. To provide a solution for this problem, a thermal impact welding process was modified and applied for the first time to join tribologically optimized polymers to metallic sheets without an additional layer of sintered bronze.

2. Experimental details

A tribologically optimized nanoparticle containing polyetheretherketone (PEEK) film was mainly used as a polymer material which has proven its excellent tribological properties in previous studies [14,15]. The PEEK/CF10 film incorporated 10 wt% short carbon fibers, 10 wt% graphite, 10 wt% titanium dioxide as well as 10 wt% zinc sulfide. This material combination was chosen due to its outstanding tribological results as observed in a previously performed material development study and also this material combination was observed to be highly suitable for slide elements based on sintered substrate materials [14]. Further films with lower short carbon fiber content (0 and 5 wt%) at same non-carbon additive content were also investigated during the parameter optimizing process especially for highlighting the influence of the carbon fibers on the adhesion quality between polymer and substrate. The thickness was 0.3 mm for each film. As metallic substrates, construction steel (DC01, DC04) and aluminum alloys (AlMg3, AlCuMg1) (which are commonly used in the automotive industry) were employed. Additional sintered bronze coated DC04 was used as a reference material.

* Corresponding author. Tel.: +49 631 205 5116; fax: +49 631 205 3600.
E-mail address: alois.schlarb@mv.uni-kl.de (A.K. Schlarb).

0301-679X/$ - see front matter © 2009 Published by Elsevier Ltd.
doi:10.1016/j.triboint.2009.12.018

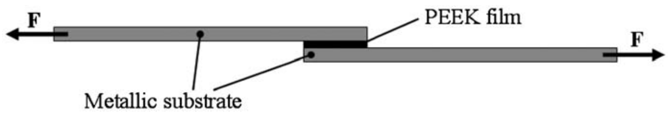

Fig. 1. Shear tension test sample.

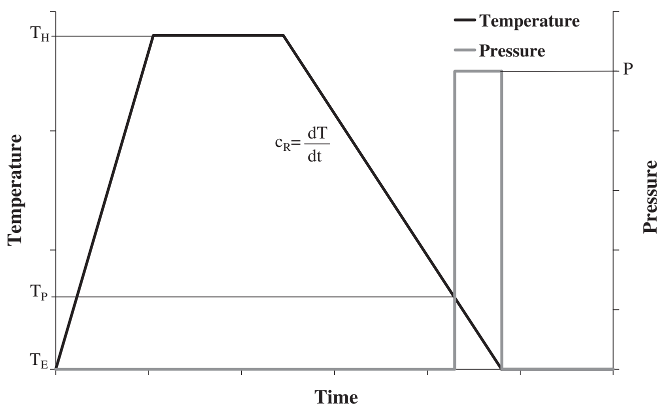

Fig. 2. Temperature–pressure–time chart for the welding of metal/PEEK-composites.

The adhesion quality was characterized by single lap specimens consisting of two metallic sheets and a PEEK foil to join them. The dimensions of the metallic parts were $100 \times 25\,mm^2$ with a thickness of 3 mm (steel) and 8 mm (aluminum), respectively. The overlapping zone had a length of 12.5 mm. These specimens were investigated in shear tensile tests, where the metallic ends of the specimens were subject to a tensile force (Fig. 1).

The shear tension strength directly relates to the adhesion quality between polymer and metal. Further single-side coated specimens with the dimensions of $100 \times 16 \times 1\,mm^3$ were produced for tribological ring-on-plate experiments.

The thermal impact welding process according to [16] was realized by the use of a hot press for which the optimal parameter setup had to be found. For welding, two metal sheets and a polymer foil were stacked in a mould and heated to the preheating temperature T_H. The polymer film melts and wets the metal due to a small preload of 0.2 MPa. To assure a homogenous molten polymer, T_H is kept stable for 7 min. Afterwards, the cooling process is initiated which is controlled by the cooling rate c_R. By approaching the press temperature T_P, the pressure P is applied until reaching the removal temperature T_E (Fig. 2). For the manufacturing of single-side coated specimens, a 0.035 mm thin stainless steel foil (X10CrNi18-10, 1.4310) covered with a release agent (PAT 808, E. und P. Würtz GmbH & Co. KG) was used instead of a second metal substrate. The later removed foil provided a smooth tribo surface.

The main process parameters varied in the process optimization had been identified in a preliminary test series and included preheating temperature T_H, press temperature T_P, joining pressure P, cooling rate c_R and removal temperature T_R. Since the substrate pretreatment is known to have great influence on adhesive techniques [17–20], the metallic substrates were subject to different pretreatments such as ultrasonic cleaning, etching, pickling, corundum blasting, anodization (for aluminum) and plasma cleaning. The varied parameter ranges for the optimization of the thermal impact welding process are described in Table 1.

Tribological ring-on-plate experiments of single-side coated metallic substrates were performed against 100Cr6 counter bodies with the variation of static load and sliding speed. The used tribometer allowed the simultaneous testing of six samples. The normal load F was varied between 15 and 30 N, the velocity v between 1 and $2\,ms^{-1}$ resulting in Fv-factors between 15 and $60\,Nms^{-1}$. The sliding distance was kept constant at 72 km for each experiment. The specific wear rate was calculated from the gravimetric loss divided by the polymer density, the sliding distance and the normal load. The coefficient of friction was recorded in-situ by a capacitive measurement of the friction force.

Table 1
Varied parameter ranges for the optimization of the welding process of PEEK with steel and aluminum substrates.

Parameter	**Min.**	**Max.**
Preheating temp. T_H	330 °C	400 °C
Press temp. T_P	305 °C	375 °C
Joining pressure P	10 MPa	90 MPa
Cooling rate c_R	2 K/min	15 K/min
Removal temp. T_E	100 °C	300 °C
Substrate pretreatment	Degreasing, corundum blasting, etching, pickling, anodization (for Al.), plasma cleaning	

3. Results and discussion

3.1. Welding process optimization

In the beginning of the experimental phase, the problem of leaking polymer melt occurred during the hot press process. This led to an insufficient amount of polymer in the joining area resulting in tensile shear strength of only 10 MPa for PEEK-welded steel sheets showing an adhesive failure. This problem could be avoided by the use of stoppers as described in previous studies [3,6] limiting the minimum polymer thickness to 0.2 mm. The limitation resulted in 18 MPa tensile shear strength being the reference for the experimental series with steel substrates. The according reference for aluminum substrates was found at 16 MPa for not-optimized parameters.

The characterization of the press parameter setup was performed with corundum blasted metal sheets. Corundum blasting was chosen as pretreatment due to the quick removal of contaminations as well as the increase of roughness regarded as promoting adhesion [19,20].

For lack of space only important results of the parameter optimization for steel and aluminum substrates are presented in this paper. For easier comparison of results, the values are standardized in the charts to a certain reference parameter set, which is marked darker.

The preheating temperature T_H was varied for DC01 steel substrates between 305 and 400 °C. A significant increase of tensile shear strength (about 40%) is observed when exceeding the melting temperature of the PEEK film at about 340 °C (Fig. 3). Below this temperature, parts of the polymer film remain unmolten which prevent a sufficient adhesion. The maximum strength was found at about 370 °C; a further increase leads to lower tensile shear strength. These results fit to those presented in earlier studies on polymer welding [21,22].

The cooling rate was varied for DC01 steel substrates between 4 and 15 K/min. The cooling rate adequately influences the length of the press period. The higher the cooling rate the shorter is the press period. According to that, decreasing tensile shear strength was found with increasing cooling rate (Fig. 4). Nevertheless, for a shorter manufacturing time the cooling rate of 6 K/min was