Polymers and polymer-based composites in tribology

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Metal-Polymer Research Institute of Bneloressian Academy of Sciences is taking an active part in research and developments in the field of polymer materials and composites. Many of these materials are devoted to use as a construction materials for machine parts, protective and decorative coatings on metals, films preventing corrosion in packaging of electronic, machinery and other components. This list can be continued by mentioning polymer capsulation coating for fertilizers, polymer filters produced by extruding and transfer of melted fibers etc.

But the major part of polymers and polymer - based composites is used as tribological materials or component of tribological units. Polymers and polymer-based materials are considered to be a very interesting object from the point of view of all the major areas in tribology.

These areas include :

- Triboanalysis (theoretical aspects of physics, chemistry, mechanics and biology of friction)
- material sciences (studics in properties of tribological materials and controlling these properties)
- tribotechnology (technological methods of controlling the friction performances of moving joints)
- triboengineering (design of efficient friction units)
- tribomonitoring (means and devices of diagnostics, control and testing the friction units)
- triboinformatics (data storage, processing and transfer in tribology)

As considering the area of triboanalysis it has been found that structure of thin surface layer in polymer material results in its tribological behaviour. Fig.1 presents data on the effect of this structure on friction coefficient when rubbing Penton against metal. Column structure results in much lower friction coefficient than spherolyte structure.

Chemical composition of polymer and type of binder in the case of polymer-base composite have also a strong effect on friction behaviour and wear mode. Fig.2 illustrates this effect in the case of scanning by microindenter along the surfaces of different polymer used as binders in composites.

Using the acoustic emission recording in the case of polmyer friction against metals it is possible to find out basic differences in emission during run-in period of friction which are related to different mechanism of fracturing the molecular structures of polymers under conditions of complicated dynamical loading in friction. Illustration of this fact is given in Fig.3 presenting acoustic emission on time relations for four polymers rubbed against steel roller at relatively mild load-veloeity conditions.

Material transfer has been found to manage basic regularities of polymer composites friction and wear. All the cases of rubbing polymers against each other or against metals result in formation of transfer film which is changing either the friction coefficient and the wear rate in the assembly. Fig.4 illustratcs the general scheme of the interface between metal and composite where transfer film has been formed.

Direction and rate of mass transfer have been carefully examined in connection with some fundamental properties of polymers e.g. cohesive energy relating to molecular structure and chemical bonding. This can be presented by diagram given in Fig.5 where the direction of transfer of polymer to polymer and to steel is plotted against their cohesive energy density. Unique self-lubricated properties of PTFE are found in good correlation with its lowest cohesive energy density.

Rubbing PTFE against other polymers results in the formation of PTFE transfer films in all the cases thus reducing the different combinations of polymers to friction of PTFE against PTFE transfer film. This is clearly illustrated by Fig.6 where friction coefficient vs time dependences are plotted for four polymers rubbed against PTFE. Stationary values of friction coefficient are the same in all the cases which shows the efficiency of using PTFE as a component of self-lubricated composites. A number of methods has been developed for improving the friction performances of polymers and polymer-based materials.

These methods are listed in Fig.7 presenting the scheme of regulating these performances. Three main areas are separated in this scheme-methods of improving the friction performances of materials by the effect of physical and chemical changes in the structure (orientation) or bonding of material as well as the introduction of solid and liquid fillers and additives, surface treatment of metal parts and using of polymer coatings, methods of regulating the friction performances in due of course of friction by external effects of irradiation or electromagnetic processes.

Let us illustrate the possibilities of above mentioned methods by the describing of the effect of PE added to pure (PCA) or filled (glass-fiber composite) materials. Fig.8 shows the effect of PE addition on the PCA friction behaviour and Fig.9 presents the similar effect on friction and wear of glass-filled material.

Polymer composites have been also found to be sensitive to mechanical treatment of their components. It can be illustrated for example by the effect of mechanical treatment of F3 (polytrifluor chlorethylene) powder on friction and wear of HDPE-based composition (Fig.10)

Data obtained in triboanalysis and material science research of polymers are considered to be a strong basis for creating the new materials used under different operation conditions.

Recently some interesting results have been obtained in studying the friction behaviour of tribological systems such as human or animal joints. In the MPRI it has been found that certain components of synovial fluid in joints have liquid crystalline behaviour. The introduction of liquid crystals based on cholesteral ethers has shown the similar effect as the use of natural synovia (Fig.11).

Data of this research have been used in the medical applications as well as in development of the efficient additives to engine oils reducing the wear, fuel consumption and other negative effects in lubrication of combustion engines.

Classification of tribological composites can be carried out according to scheme presented in Fig.12 where the main types of composites are shown with schematic pictures relating to structure and type of filler used. Seven characteristic types can be classified in this scheme, — filled polymers, composites based on blends of thermoplastic polymers, blends of thermoplastics and thermosets, wooden-based composites, metal-polymer compositions, organo-and carbon fibre-reinforced composites, laminated composites and coatings.

Table presented in Fig.13 can be a good illustration to properties of different types of polymer composites developed in MPRI and used in various industrial applications (bearings, chain gears, sealing elements, guides etc.)

Accumlation of data obtained in polymer tribology has created the possibility to formulate the efficient procedures in development of materials and design.

These material and design approaches can be realized both in the level of composite structure as well as in the level of friction unit design.

Fig.14 illustrates the structure of multifunctional self-lubricated composite where various structural components result in self-lubricating ability af different load-velocity conditions. At low loads such additives as oil and thermoplastic filler are working. Later with the increase in temperature thermally degradating fillers are efficient. In most severe conditions soft metal filler is working together with reinforcing components.

Fig.15 presents the design of polymer bearing with the elements preventing seizure under severe friction conditions due to the feed of oil to friction surfaces resulted by thermal expansion of the inserts containing oil and gas mixture.

Resuming the review of polymer and polymer-based tribological materials it should be mentioned that their using open the new possibilities in creation of tribological components in various field of industry. Further progress is possible when synthesizing the achievements of all the areas of triboligical knowledge, accumulation of data and information exchange providing rapid technology transfer from laboratories to engineering practice.