Smart Coatings and Green Tribology

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1. Introduction

Green tribology is defined as the science and technology of the tribological aspects of ecological balance. Dealing with the optimization of tribocouples, green tribology affects the economy and environment by reducing waste and extending equipment life, improves technological and environmental balance, and thus the sustainability and safety in the human society. One of green tribology's principles touches the environmental implication of coatings and lubricants, development, optimization and implementation of ecology friendly manufacturing and implementation of coatings [1], [2], [3].

Alloys, polymers, ceramics, composites – both bulk materials and coatings – were developed to serve modern performance requirements. The search for material which to outfit performance requirements, and to satisfy the necessary boundary conditions, has lead to the development of **smart materials** whose structure and composition (on a macro, micro or nano level) can be intentionally manipulated to affect the properties in a controlled manner. Smart materials, also called programmable or designed material [4], [5]**,** [6], are result of the historical development the material science, beginning with the construction and functional materials and arriving gradually to the intelligent or smart materials. They have one or more properties that can be changed in a controlled manner by external stimuli, such as stress, temperature, moisture, pH, electrical or magnetic fields, and achieve a specific functionality in a system.

Combinations of various technologies are necessary for production of components with predetermined performance by synthesis of designed microstructure and composition, useful in tribological applications.

Tribologists have the task to keep the destruction as small as possible or to stop it, in order that the system comes to the equilibrium process between destruction and regeneration. Exactly this happens in the process of selective transfer of material between friction surfaces. In the case of frictional coatings production, this phenomenon is assisted by rubbing of brass against steel under the special conditions of selective transfer. The procedure takes concern of antifriction nonabrasive treatment of steel and cast-iron surfaces of rubbing components under special lubricant condition – metal-cladding additives.

In the contact zones emerges reactive coating deposition with special properties. Both the content and the structure in the friction surfaces are changed, and the tribological system can bear higher loads at the influence of various wear processes.

The paper deals with green tribology in the aspect of wear reducing frictional coatings and regeneration of worn surfaces without joint dismantling**.** Copper frictional coatings in the case of nonabrasive treatment of steel surfaces are being considered. Procedures of study of copper or brass frictional coatings through selective transfer of materials are considered.

2. Friction under Selective Transfer mode

Consideration is given to the selective transfer phenomenon in friction couples consisting of copper cooperating with steel in the medium of special lubricant (glycerol or FPT1) and to the creation of "servovite" layer, namely a self-formed layer serving to prolong the life of the friction unit [7],[8]. The smart coat formed directly on the rubbing surface leads to highly improved wear-resistance with implications in combustion engine cylinders (even racing car engines), heavy loaded friction units, aircraft units, etc. The selective transfer friction prevents dislocation accumulation in surface layers, in opposite to the case of boundary friction.

2.1. Frictional Coating Deposition

D. N. Garkunov and G. Polzer are of the first researchers in theory and practice of selective transfer of material during friction coating deposition [7], [8], [9], [10]. Common works were carried out connecting the Tribology Center in Sofia and the Tribology Group of Prof. Polzer in Zwickau, and recently in Schoenfels, Germany.

Based on equations of theoretical physics, Prof. G. Polzer had derived equations of selforganization at friction. Always when destruction problems are available in nature, there are two possibilities for the whole system: either simultaneous growth processes, which involve equilibrium between destruction and regeneration, or, exponential destroying of the whole system, in our case the tribological couple [7], [8]. What is friction coating deposition? A steel element (e.g. a shaft) to be coated is both subjected to rotation and to the pressure of a brass stick in the presence of a special lubricant, forming a bronze-steel tribocouple (See the principle scheme in Fig. 1).

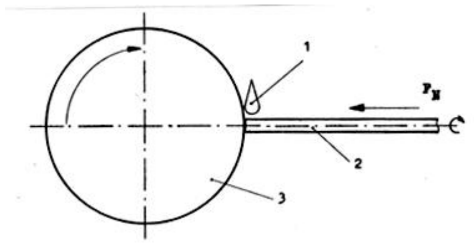

Figure 1 Scheme of copper deposition (1 - surface active liquid; 2 - brass rod; 3 - shaft to be coated)

The film forms on the friction surfaces in the bronze-steel tribocouple with glycerin lubrication passing firstly through dissolution of the bronze surface, where the glycerin acts as a weak acid. The atoms of the elements (tin, zinc, iron, aluminum) absorbed in bronze outgo into the lubricant, as result the bronze surface is enriched with copper. Friction deformation of the bronze surface causes new passing of elements into the lubricant, so the bronze layer is purified and it nearly contains only copper. Its pores fill with glycerin. Glycerin is reducer for copper oxides, hence the copper film is free form oxides; it is very active with free ions and is highly adhesive for the steel surface. The steel surface is covered by thin copper layer. Self-organization and selective transfer of copper to steel take place. Before the stabilized selective transfer, the process goes on until steel and bronze are coated by 2 µm copper layers [10]. Mechanical and chemical transformations take place; e.g. formation of surface active substances on the friction surfaces; they interact chemically with the surfaces and form chemisorbed layers (see Fig. 2).

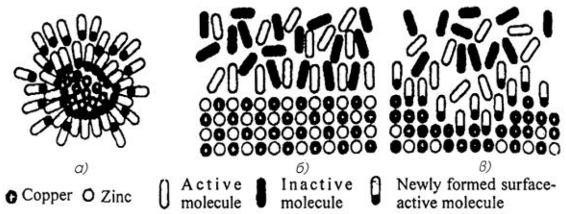

Figure 2 Formation of micelles and interaction of surface-active substances with bronze (as per [10])

Some results of the basic studies and application in the area of copper frictional coatings are presented below.

A self-organization in the system brass-glycerol-steel is observed and the obtained film – a coat with significant change of wear-resistance. Major result is the low wear of components coated under condition of selective material transfer mode. Important is also the reduction of the concentration of hydrogen at the frictional surface and, respectively, the lower hydrogen wear. It is highly important for practical applications that the inclination for welding and seizure [8] between the friction surfaces is significantly lowered under conditions of selective transfer. A considerable practical result is the possibility for dismantling-free restoration of worn units/couples.

2.2. Experimental work

The phenomenon of direct coating deposition is assisted by the rubbing/deposition of brass under the special conditions of selective transfer of material. Different processes result. In the contact zones emerges reactive coating deposition with special properties: Copper is rubbed on the steel friction surfaces with totally different electro-chemical potential, and secondly, not only the content but also the structure in the friction surfaces is being changed [8].

The compress forces at the rotation of the brass stick involve great pressure in the contact zone between stick and basic material due to the relative small contact surface, hence a positive gradient of the shear strength in depth direction of the friction surface according to I. V. Kragelsky [11].

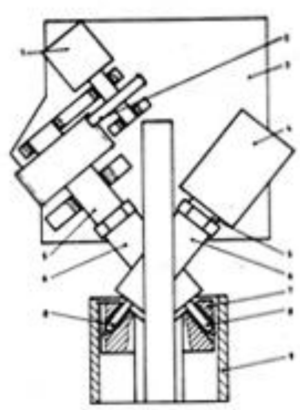

Figure 3 MBZ 3A Brass-coating device for sliding bushes (application in lathes)

As a result, a tribological system appears which can bear higher loads at the influence of various processes. Different machines were designed and constructed at the Department Tribotechnik in Zwickau' Higher Technical School, corresponding to the principles of the frictional deposition and the ideas of the selective transfer. Many pieces of the devices „MBZ 1" for shaft coatings and „MBZ 3 A" for application in rotating machines were manufactured (see Figs.3, 4, 5), e.g. the „MBZ 3 A" for engine cylinders was produced in 30 items. Unfortunately there is not sufficient use of the advantages of the deposition of copper frictional coatings in the overall practice.

Figure 4 View of the brass-coating device MBZ 3A

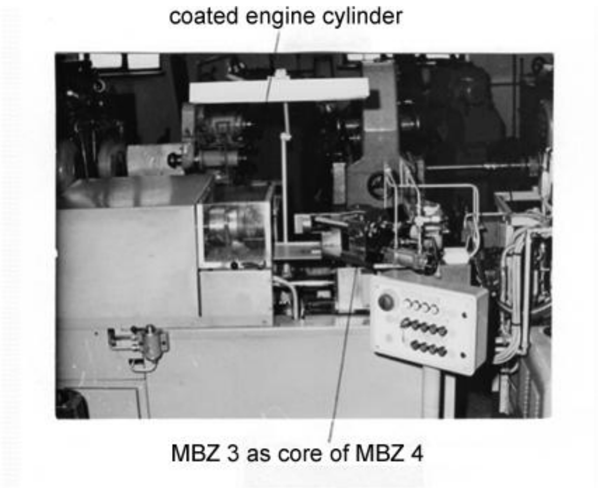

Figure 5 The brass-coating device applied in an automatic machine

Some diagrams referring to a part of the basic new results are presented below. In Fig. 6 is given the variation of hardness in depth; the strengthening can also be obtained at different rotation speeds.

Fig. 7 shows the reduction of hydrogen concentration of the friction surface in depth. The hydrogen wear results from synergetic interaction of various surface phenomena: exoemission, adsorption, frictional destruction, which provide hydrogen extraction from the frictional surfaces. Thermal gradient is also formed, as well as electrical and magnetic fields; this leads to hydrogen diffusion in the metal, hydrogen concentration in the subsurface layer and rapid wear of this layer [8], [10]. Metal defect formation in the friction deformed layer also increases the H_2 concentration and augments the wear. Frictional coatings, however, improve significantly the wearresistance against hydrogen wear [8].

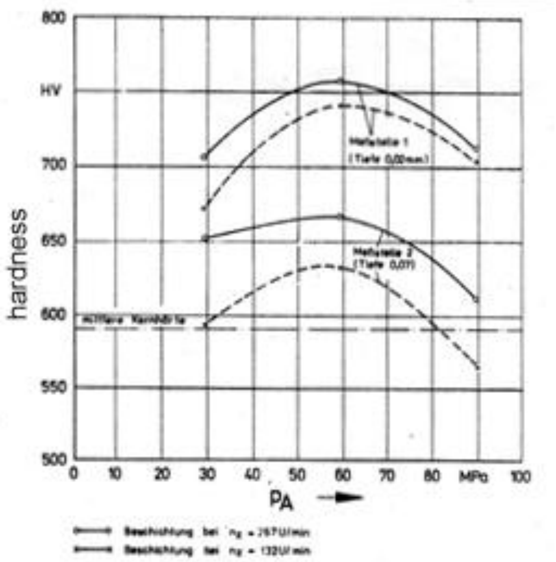

Figure 6 Hardness in different depth after frictional coating deposition on steel: meas. point 1 – depth 0,02 mm; meas. point 2 – depth 0,02 mm; continuous line: coating deposition at n_z = 267 rev/min, dash line: coating deposition at n_z = 132 rev/min

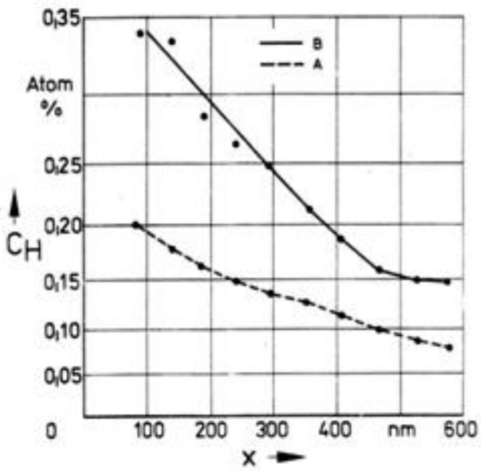

Figure 7 Reduction of H_2 concentration at the frictional surface in depth

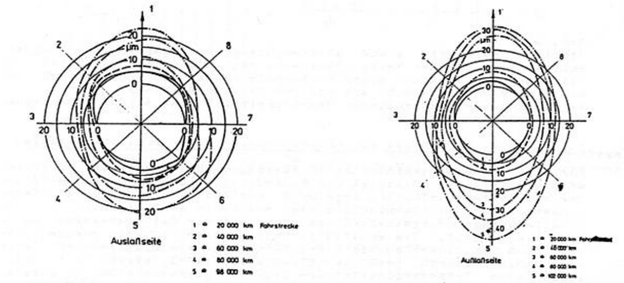

Figure 8 Wear distribution in upper dead point of engine cylinder after different sliding paths: for cylinder with frictional brass coating (left) and uncoated (right)

By means of brass frictional coating in different constructions of steel and cast iron it can be obtained not only the 10 - 20 % lowering of friction force, but also a changed wear distribution, which is to be seen, e.g., for the upper death point in engine cylinders of Ottomotors after various completed paths (see Fig. 8). This was the reason that the brass frictional coatings were successfully applied in the practice of the company Peißig in Zwickau, especially in highly loaded race motors for more than 20 years too.

3. Discussion and Conclusion

Green tribology should be integrated into world science and make its impact on the solutions for worldwide problems. Being a new field, green tribology has a number of challenges. A basic one of them, **minimising the wear**, is being discussed in above investigation of wear reduction possibilities through frictional coatings.

The study of frictional coatings linked above to the concept of smart material can be summarized in the following:

- Self-organization in the system brass-glycerol-steel under selective transfer is observed. It prevents dislocations accumulation in surface layers (unlike the case of boundary friction), a low shift resistance is obtained and a surface-active substance is formed which plasticize the metal, so dislocations moving to the surface are discharged. Hence, the obtained film – a designed or controllable coat with significant change of wear-resistance – can be intentionally manipulated to influence its properties during deposition in friction.

- Important features of the coating deposited during friction under selective material transfer mode: Low wear of components at nonabrasive treatment of steel/cast iron, and low hydrogen wear of the coated surfaces; lower inclination for welding and seizure between the friction surfaces; improved longevity of the friction unit; possibility for dismantling-free restoration of worn units/couples.
- The frictional coatings are eco-friendly as coat deposition (pollution-free technology) and as application through the improvement of the lifetime of friction units (energy and material saving by wear-reduction and by the dismantling-free restoration of worn units).

The practical implementation implications in combustion engine cylinders (even racing car engines), heavy loaded friction units, dredgers, mining machines, aircraft and spacecraft units, etc. of brass-copper frictional coating is of extreme importance and was realized in Germany, Russia, Kazakhstan, Poland, etc.

Being interdisciplinary, the study and application of technologies for frictional coating formation, layer growth techniques, surface texturing, etc. involves intervention by specialists of different sciences. The work and collaboration between scientists of Russia, Germany, Poland, Bulgaria, Mongolia and Vietnam in this field was carried out by the International Council for Selective Transfer and Frictional coatings, established in 1990 in London.

Look in the future

It is great time that we provide major support to help science and industry tackle implementation of smart materials and coatings. **Frictional coatings**, for example, are not enough popularized and their opportunities are not sufficiently utilized. The principle of Green Tribology could be of great use to meet the growing expectations of our society towards its optimized behavior to the environment.

The way of bridging education, research and innovation thereby creating the conditions for increased relevance and utilization of research activities should be more actively developed. We, banner bearers of tribology, should direct efforts in the development of universities' capacity to lead and prioritize research results to get utilized.

A part of this is the enhanced mobility between universities following the Project of the first Tribology Network, coordinated by Bulgaria and relating 10 European countries, under the program CEEPUS Project CIII-BG-0703-01-1213 "Modern Trends in Education and Research on Mechanical Systems – Bridging Reliability, Quality and Tribology" running already in the second year. Knowledge should be spread and **networking** is a key to enhanced possibility for research results to help quality and standard of life grow.

4. References

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