ADVANCED POLYMERS USED IN PLAIN BEARINGS

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Rezumat. *Odată cu dezvoltarea fără precedent a industriei, bazată pe sisteme automate, numărul elementelor în mișcare a crescut exponențial. Asigurând rularea fără lubrefiere chiar și la viteze mari, fără zgomot, cu randament ridicat, în game largi de temperaturi, aducând cu sine și avantaje de preț semnificative, fiind insensibile la contaminanți externi și vibrații, materialele compozite pe baza de polimeri asigură avansul tehnologic cerut de Industria 4.0.*

Abstract. *With the unprecedented development of the automated industry, the number of moving elements has grown exponentially. Ensuring the smooth running, even at high speeds, without noise, with high efficiency, in wide temperature ranges, bringing with them significant cost advantages, being insensitive to external contaminants and vibrations, the composite materials based on polymers ensure the technological advance required by Industry 4.0.*

Keywords: Polymer, bearing, UHMWPE, Nylon, PTFE, POM

1. Introduction

Plastics are synthetic products of an organic, inorganic or mixed nature, which can be easily processed into various forms, hot or cold, with or without pressure.

The first plastics were produced from the transformation of natural materials. In 1859 vulcanized fibers appeared, in 1869 celluloid appeared and in 1897 galite. The first synthetic material to appear (1908) was the phenolformaldehyde resin called Bakelite. There are numerous processes for the manufacture of plastics. A bucket, a bottle, a motorcyclist's helmet, a windsurfing board are all made of different types of plastic. For each object, you must choose the plastic material that has the most suitable qualities: suppleness, rigidity, shock resistance, elasticity, transparency, light weight. In general, the product that starts in the manufacture of plastics is oil, a product obtained in oil refineries. Petroleum is a mixture of different hydrocarbon molecules. This mixture is brought to high temperatures in the presence of water vapor, which causes the breaking of hydrocarbon molecules and obtaining smaller molecules, ethylene molecules. Ethylene is the molecule on which the entire plastics industry is based [1], [2].

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There are two major families of plastics: thermoplastics and thermosetting ones. The first category includes plastics that melt if heated, some even at 70 ° C, others at up to 300 ° C. When hot and liquid, these materials can be molded or extruded, ie drawn into wires or sheets. As it cools, the thermoplastic materials solidify and retain their new shape. These plastics are mainly used for the mass production of objects, such as bottles, buckets, etc. Instead, the thermosetting ones harden on heat. Thus, they are cold molded to the desired shapes and then heated to harden. Or they can be left to harden after a special product is added. Heat-sealed plastics are used in the manufacture of hand-processed objects or those that require careful manufacture. This is how boats, body parts, bumpers, etc. are made.

The basic constituents of plastics are organic polymers [3], [4], [5]. A polymer is a pure chemical resulting from a polymerization. Polymerization is the process by which several identical unsaturated molecules come together to form a macromolecule. In polymerization reactions "n" molecules of substance "M" combine to form macromolecules that have the same composition as the polymerizing substance, but the resulting product has completely different properties. The polymerization reaction can be written very simply: nM Mn. The molecule of unsaturated raw material M is called monomer (fig.1).

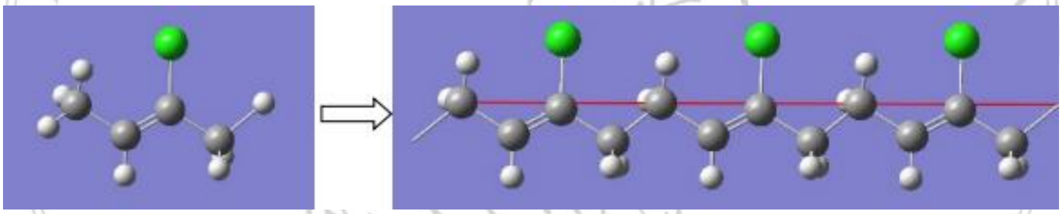

Fig. 1. Polymerization.

Polymers consist of a large number of fundamental units, monomers, which are organic molecules whose core consists mainly of a carbon atom (or silicon in the case of siliconized polymers). Monomers are basic elements of all polymers, whether they are biological macromolecules (DNA, RNA, collagen, keratin, etc.), natural polymers (latex, cellulose, etc.), or synthetic polymers (plastics, elastomers). , etc.)

1.1. Plastics classification

The plastics used in the technique are divided into two groups:

Thermoplastics, which by repeated heating pass into plastic (polystyrene, polymethacrylate, celluloid, polyamide, polyvinyl chloride). The parts of these materials are obtained by pressing and casting, having a high productivity.

Thermoreactive, which by repeated heating no longer passes into the plastic state (unsaturated polystyrenes, phenolpholaldehyde resins, etc.). the parts in this case are processed by pressing.

Polymeric materials are materials that include polymers and various additives with a well-defined role. Polymers are molecular substances, of nature: inorganic, organic or mixed.

In the construction materials industry, organic and mixed polymers are used, because during the manufacture only they go through a plastic phase which facilitates their processing. That is why these materials are also called "plastics" (inappropriate name, because for polymer materials used in construction not plasticity is the fundamental characteristic but their elasticity, flexibility and rigidity, depending on the field of use).

Depending on the properties of polymer materials, they can be divided into:

- elastomers - formed of one-dimensional molecules and characterized by high elasticity;

- thermoplastic plastomers - made up of two-dimensional macromolecules and which reversibly increase their plasticity when heated;

- thermoreactive plastomers - made up of two-dimensional macromolecules but which when heated pass into three-dimensional structures and become rigid.

1.2. Polymer properties

The physical and chemical properties depend on:

- composition;
- structure;
- degree of polymerization;
- orientation of macromolecules.

Therefore, some of these properties vary within very wide limits. So:

- the apparent density can be between 15 and 2000 kg / m3;
- thermal conductivity is generally low, which determines their use in the execution of thermal insulation.

Disadvantages of polymer materials:

- low thermal stability;
- high coefficient of thermal expansion (about 2-15 times higher than steel: 25 · 10-6-125 · 10-6);
- aging over time - is manifested by loss of elasticity and plasticity.

Mechanical properties:

Mechanical strengths are dependent on the strength of the bonds inside the molecular chains and between the chains, but especially on the degree of polymerization or polycondensation.

Usually the mechanical strengths of plastics are of the same order of magnitude as the strengths of ordinary construction materials; in some, the compressive and tensile strengths are similar to those of metals (bronze, cast iron and even steels).

Most of these materials have a high shock resistance, considerable wear resistance and appreciable durability, if used properly.

They can easily take the desired shape due to the different processing methods.

It does not require any processing during construction.

Use and cleaning are easy.

Staining, possibly in several colors, can be done very well either in the mass of the material or on its surface, so that the material does not fade.

They are waterproof.

They are resistant to the action of chemicals.

They have good electrical insulation properties.

Disadvantages considering mechanical properties:

- they are not resistant to high temperatures, the softening temperature being between 50 ° C and 100 ° C;

- the coefficient of thermal expansion is 2-8 times higher than that of ordinary construction materials.

1.3. Additives for polymer materials

In order to give the polymer materials certain characteristics, different additives are used to obtain them.

After the effect produced in the finished product, the additions are classified in:

Plasticizers - have the role of increasing the elasticity, plasticity and shock resistance of the polymer, as well as to preserve its physical and mechanical properties, in a longer temperature range; substances with molecules smaller than the macromolecules of the polymer are used as plasticizers.

The action of plasticizers is explained by their intercalation between the macromolecules of the polymer (fig. 1), causing their deformation or removal (depending on the quantity manufactured). In the first case the elasticity is improved, and in the second the plasticity of the polymer.

Stabilizers or antioxidants - are additives that delay the aging process of polymers.

The action of stabilizers is different depending on their chemical nature (prevents the diffusion of oxygen, absorbs radiation that accelerates oxidation or reacts more easily with oxygen than polymer).

2. Types of polymers

2.1. Polymer materials derived from natural products

Protein-based materials - casein left over from separating butter from milk; by treating the products resulting from the pressing of the mixture of casein, pigments and fillers with formic aldehyde results in a hard material called "galalite"; electrotechnical devices were manufactured from galalite.

2.2. Cellulose-based materials - the main ones are:

- volcanic fiber - is obtained from hydrated cellulose by treatment with a concentrated solution of zinc chloride; from vulcan fiber are manufactured plates for safety panels, gaskets, brake shoes, gears, rollers for conveyor belts;

- cellulose esters - are obtained by treating cellulose with a mixture of sulfuric and nitric or acetic acid; it is used especially dissolved in volatile solvents, to obtain quality varnishes and enamels; when mixed with solvents in smaller quantities results in a viscous solution called "collodion", which is drawn into threads and films that harden after the evaporation of solvents and remain flexible;

- celluloid - is obtained by hot pressing of cellulose nitrates with 10-11% nitrogen; it is used to make plates, handles, etc.

Rubber-based materials - natural rubber is a polymer of isoprene found in the latex of some trees, from which it is obtained by concentration and coagulation; rubber products are manufactured with the addition of fillers and vulcanizers; are manufactured: tubes, conveyor belts, transmission belts, etc.

2.3. Synthetic polymer materials

According to the method of obtaining, synthetic polymers are classified into:

Polymerization polymers:

- polyethylene - obtained by polymerizing ethene at different pressures in the presence of catalysts; it is used in the form of thin sheets for the protection of scaffolding (tubes);

- polypropylene - obtained by polymerizing propylene; is used for hot fluid transport pipes;

- polyisobutene - obtained by polymerizing isobutylene in the presence of catalysts at low temperatures; mixed with carbon black and bitumen it is used in the form of sheets as a waterproofing material;

- polystyrene - obtained by polymerizing styrene; it is used in the form of white or colored tiles for wall cladding, building windows. It can be expanded or extruded.

- polyvinyl chloride - obtained from the polymerization of vinyl chloride in the presence of catalysts; it is used in the form of PVC pipes for electrical installations, water pipes, gutters, pipes, material for fittings, etc .;

- polyvinyl acetate (PAV) - obtained from the polymerization of vinyl acetate; is used in the form of emulsion in non-plasticized water (ARACET E) or plasticized (ARACET EP) for: paints, semi-washable wallpapers, adhesive in the wood industry, fixing parquet on the substrate, etc .;

- methyl polymethaculate (plexiglass) - obtained from the polymerization of methyl methaculate in the presence of catalysts; it is used in the form of sheets, strips, products shaped in bright decorative works, as acoustic screens and in the form of corrugated roof tiles.

2.4. Polycondensation polymers

- phenoplasts with different degrees of polycondensation - obtained by polycondensation of phenols with aldehydes; they are used to obtain varnishes used in electrical engineering and to anti-corrosion protections of metals, as adhesives in the manufacture of plates (PAL, PFL);

- aminoplasts - obtained from the polycondensation of amines (melamine) with formic aldehyde; they are used as adhesives in the wood industry and in obtaining resistant varnishes (melamine PFL);

- polyamides - obtained by polycondensation of diamines with dicarboxylic acids; are used in the form of fibers and fabrics but different names: nylon (USA), relon (RO), capron (Russia);

- polyesters - obtained by polycondensation of polyalcohols with polycarboxylic acids; they are used to obtain paints, enamels and varnishes for finishes and anticorrosive protections, binders for the preparation of mortars and concretes with very good mechanical and chemical resistance;

- epoxy resins - obtained by polycondensation of ethylene oxides (epoxides) with polyphenols, dialcohols or amines; it is used as resistant adhesives for different materials (concrete, metal, glass, wood, etc.), on industrial floors, repair of concrete elements, protective layers;

- polyurethanes - obtained by polycondensation between diocytes and alcohols; it is used as flexible foams for upholstery and rigid foams for thermal and sound insulation;

- silicones (mixed nature polymers) - obtained by polycondensation of silicic acids with organic substances; use as liquid silicones and as lubricants and to obtain very resistant varnishes; silicone rubber is used for sealing gaskets that work in variable climates, silicone foils (like scotch) are used for sealing.

3. Sliding bearings using polymers

The application areas of sliding bearings are very wide, ranging from applications that offer low loads and high speeds to large loads with moderate or low speeds. The types of movement that can be addressed by slings on such bearings include, in addition to the usual ones and those of pivoting, superimposed movements or those that require operation in conditions of periodic or non-periodic intermittent movement.

Sliding bearings that use modern materials, such as composites, are used successfully when the design imposes small contact surfaces at the same time with significant loads. A characteristic often used in the case of this type of bearing is related to the vibration behavior. It has excellent damping, especially in the case of static loads, such as systems where mechanical shocks often occur. Also, a major advantage is the ability to work with a low level of lubrication or even in its absence, promoting the possibility of use in environments with "clean room" requirements.

Due to the advantages they propose in some types of applications over rolling bearings, the major manufacturers of tribological equipment (Schaeffler, SKF, Timken, Igus, etc.) offer materials and products divided according to:

■ loading conditions	■ movement conditions	■ adjacent construction	■ environmental influences
- type of load	- type of movement	- mounting space	- temperature
- loading direction	- direction of movement	- shaft, housing	- the influence of the environment
- the size of the load	- frequency of movement		- contamination
■ lifespan			- lubrication

The classification of sliding bearings is done according to several criteria, presented below:

- according to the friction regime (dry, limit, mixed, fluid);
- according to the direction of the taken force (radial, axial, axial-radial, radial-axial);
- according to the shape of the friction surface (cylindrical, conical, spherical);
- according to the way of achieving fluid friction (hydrodynamic (HD), elastohydrodynamic (EHD), gas-dynamic (GD), hydrostatic (HS), gas-static (GS), hybrid (hydrostatic-hydrodynamic));
- by position on the shaft (end, intermediate);
- according to the type of rotational movement (complete, oscillating).

The advantages of sliding bearings are reduced to the following:

• more precise guidance of the shafts towards the housings, due to the smaller number of parts towards
rolling bearings;
• The lubricant film largely absorbs shocks and vibrations and contributes to the reduction
noise;
• have smaller radial dimensions than rolling bearings;
• have longer operating times than rolling bearings and can operate at high and very high speeds.

The disadvantages of these bearings are:

• coefficients of friction (friction losses) higher than with rolling bearings;
• large axial direction gauge;
• lower degree of standardization than in the case of bearings and high lubricant consumption.

The fields of use of sliding bearings are smaller than of bearing bearings and it is recommended in those cases where the rolling bearings cannot be used: at very high speeds, at which the durability of the bearings is reduced; to trees that must be guided very precisely; in the case of bearings subjected to shocks and vibrations; when very small radial dimensions are required; at very large overall dimensions, for which no bearings are made in series and where the sliding bearings are cheaper; in conditions of humidity and aggressive environment, in which rolling bearings cannot be used; for slow-moving and low-demand mechanisms, where the cost of a sliding bearing is lower than that of a bearing [6]… [11].

3.1. Friction types

Friction represents the interaction of a moving body relative to another body, and the friction force represents the resistance opposite to the movement or the tendency of movement between the two bodies, the mechanical work of the friction forces being transformed into heat.

The types of sliding friction are the following: dry, limit, fluid, mixed.

Rigorously dry rubbing is performed in laboratory conditions (vacuum), ie in the absence of any contamination of surfaces in contact with fluid or solid media and is characterized by the highest energy losses.

The technically dry friction is frequently encountered in the technique and is characterized by the presence of a gaseous environment and a reduced contamination of the surfaces in contact with foreign bodies.

It is characterized by high coefficients of friction and significant wear, its laws being presented below: the friction force Ff is directly proportional to the normal force Fn at the contact surfaces ($Ff = \mu Fn$); the coefficient of friction μ does not depend on either the size of the contact surface or the relative sliding speed but only on the torque of materials in contact. Dry friction is due to the engagement of the micro asperities of the surfaces of the two parts and the points of molecular adhesion; micro asperities are subjected to crushing and shearing.

The limit friction is characterized by the presence on the surfaces of the parts in contact of a very thin layer (10-3 ... 10-2 μm), but strongly anchored, of foreign bodies, which prevents the formation of molecular adhesion points, but does not remove the micro asperity gear. . The friction forces, under the conditions of limit friction, can be 2 ... 3 times lower than at dry friction, respectively the wear is much lower.

Fluid friction occurs when a sufficiently thick layer (lubricant) of lubricant is interposed between the surfaces of the parts, so that direct contact between the surfaces of the two parts is excluded. Friction takes place only between the layers of lubricant, the friction losses being very small and the wear is practically non-existent. This is the ideal regime, whose study is based on the laws of fluid mechanics (hydrodynamics of viscous fluids). For fluid friction, a conventional coefficient of friction is defined $\mu = hv / pmh$, where h is the dynamic viscosity of the lubricant, v - spindle speed, pm - average pressure, and h - thickness of the lubricant layer.

Mixed friction occurs when the thickness of the lubricant film is too small or the surfaces of the parts are roughly machined, so that some microasperities come into contact, breaking - from place to place - the lubricant film. Friction losses are higher than fluid friction.

Selection by bearing type

Depending on the type of bearing and its geometric structure, there are several possibilities to support the load and the degrees of freedom of movement. By changing the bearing geometry, other functions can be performed, such as compensating for alignment differences.

3.2. Operation limits

The load-bearing capacity of a sliding bearing depends on the material of the sliding layer, the supporting body, the geometry of the bearings and the mechanical construction of which it is a part. The data and recommendations in the data sheets provided by the manufacturers must be observed.

Pressure-velocity (PV) factor is a key design parameter in the proper sizing and selection of assemblies that use polymeric parts for tribological purposes. Although you will find it listed for most polymers used in industry, PV is generally overlooked when considering the loads conveyed by screw-nut assemblies, being more commonly used in radial bushings and linear guide applications. PV effectively defines the performance that can be achieved for a bearing made of polymeric material. Plastics have a maximum PV value limited by the intrinsic properties of the material. The PV of a system can be calculated according to the operating conditions. Simply, the higher the load applied to the assembly, the slower the application must be, in order to avoid exceeding the material limit. Conversely, starting from the speed to be reached, the permissible load limit can be determined.

To improve the PV, special additives are used, which must also bring improvements in structural and tribological properties. The tests are most often performed using a disk of material that slides on a steel surface. By changing the load and speed on the test sample, the point of inflection of the wear values can be determined and from here the PV limitation of the material can be determined. While a base resin may have a certain PV, by adding lubricants and other compounds, this value can be greatly improved. Not only the material can be improved to be used in a certain application, but also the design itself, the designer being thus directly involved in the success of the mechanical solution.

The curve between pressure and velocity for a given material can be represented in the form of a graph (see figure below). In the case of a bearing for a linear guide, the pressure is the normal force applied on the bearing surface of the bearing, and in the case of a nut, it is defined as the axial force applied on the contact surface of the nut. Speed is defined as the sliding speed between the contact surfaces of the bearing.

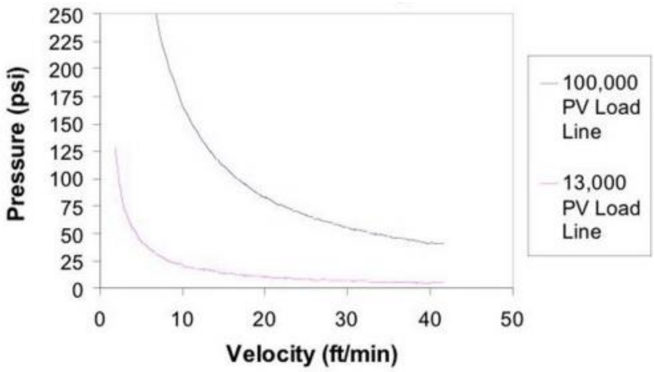

Fig. 2. Pressure vs. Velocity [12].

3.3. Wear

If the service life is the decisive selection criterion, a simple estimate of the sliding distance achievable in the case of maintenance-free and low-maintenance bearings can be made. The sliding distance is the distance covered by the sliding body along the sliding surface.

The process of wear can be defined in several ways, but the most general and most accepted refers to the difference in mass or volume before the start of the process and after its completion. The mechanical forces, the mechanical work produced by the friction forces, the impact forces, the fatigue of the material due to the stress in the contact area, the cavitation forces, induce the damage of the surfaces of the members in contact. The result is the loss of adhesion to the surface of the parts and the production of fragments of material. Chemical wear has a similar character but produces effects on a smaller scale.

In the case-study of the wear process, three main ways can be followed to understand and determine the phenomena. The first path is that of generic extrapolation starting from the generally accepted case of the model with two non-interactive terms. Friction is, as a first approximation, of two kinds: interfacial and cohesive.

A more pragmatic alternative, it treats wear and tear starting from its origin and consequences. Therefore, abrasion, transfer, seizure, chemical wear, erosion, fatigue wear, delamination, etc. are treated.

A third alternative is one that recognizes the extremely varied spectrum of the response of polymeric materials and focuses on the response of the material combined with deformation in the contact areas. In this way, wear can be divided according to the response of the material, or grouped into classes: elastomers, resins, crystalline and semi-crystalline polymers.

Polymer contact in the case of bearings is prone to seizures; this aspect is notable for all non-crosslinked polymers in which molecular mobility and flow are not constrained by the binding process between molecules or crystalline phases. When a polymeric contact reaches temperature close to the crystalline transition, the value of Young's modulus deteriorates with hardness measurement. Such a process can be viewed by considering the energy dissipation rate at the contact level. The premise is that, at the transition, there will be a loss of the level of persistence of the asperities. A simple prediction of friction is:

$$F = \tau A \quad (1)$$

where:

- τ is the interfacial shear stress;
- A, which is approximately inversely proportional to the hardness, is the contact area.

The transfer of polymeric material is of maximum significance, because the properties of this layer significantly determine the tribological properties of the pair of sliding materials. The transfer of material is more pronounced in certain polymeric materials and less or not at all (polypropylene) in others. The materials that clearly transfer material are polytetrafluoroethylene (PTFE), UHMWPE and POM (polyoxymethylene). The deposited layers promote a very small dynamic friction coefficient, with an increase in the level of wear and the static friction coefficient. The improvement of the dynamic response is mainly due to the shear action from the surface of the material that generates the alignment of the interface areas [13]…[18].

To cover some disadvantages (low wear resistance, low temperature resistance, high coefficient of friction, resistance to chemical and environmental factors, etc.) that some polymers have, composites that unite into one have been developed. material the desired technical properties of several materials. The compounds used are of organic origin (polymers), but especially inorganic (metal particles, fibers and porous supports). For example, the use of 10% fiberglass particles in a mass of PTFE reduced the wear rate by three orders of magnitude. Polymer blends are another example of improving wear resistance.

4. Case-study

4.1. Machine tool bearing

Polymer axial bearing, made of ultra high density polyethylene and 1.4301 steel counterfeit (SS304). It ensures a lubrication-free ride, with negligible stick-slip and good vibration damping (Fig.3).

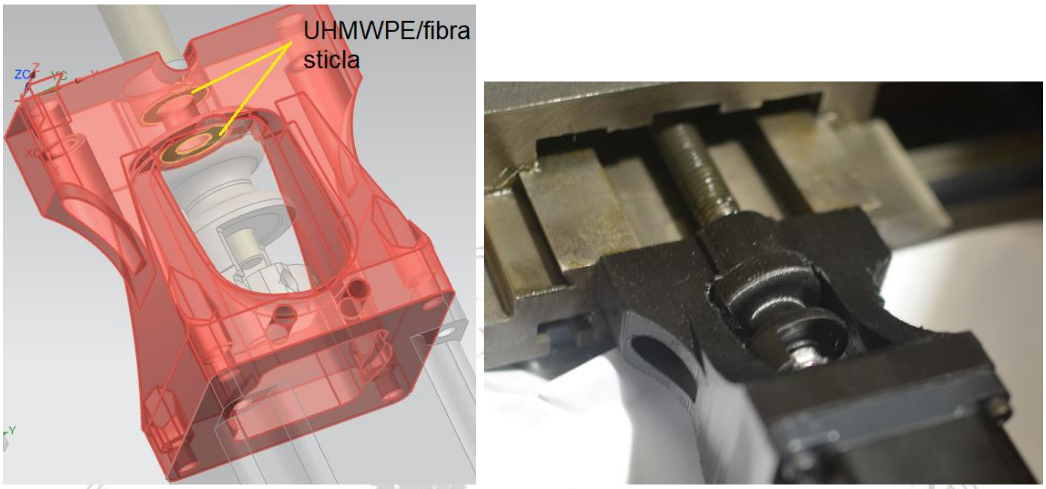

Fig. 3. Polymer axial bearing.

4.2. Linear bearing for a Pick and Place machine

Mechanism with one-way flexibility and increased rigidity in all other degrees of freedom (flexure) made of polyamide polymeric material with high wear resistance (Fig. 4).

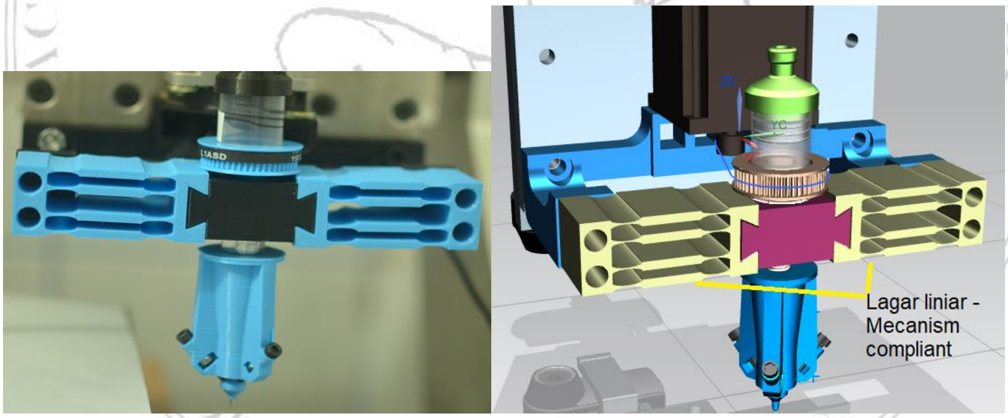

Fig. 4. Linear bearing using polyamide polymeric material.

4.3. Axial bearing for a production machine

An example of drive system with movable nut for fast multi-axis movements on the same screw is presented in Fig. 5. The nut and axial bearing are made by polymeric materials POM and UHMWPE respectively, reinforced with carbon fibers.

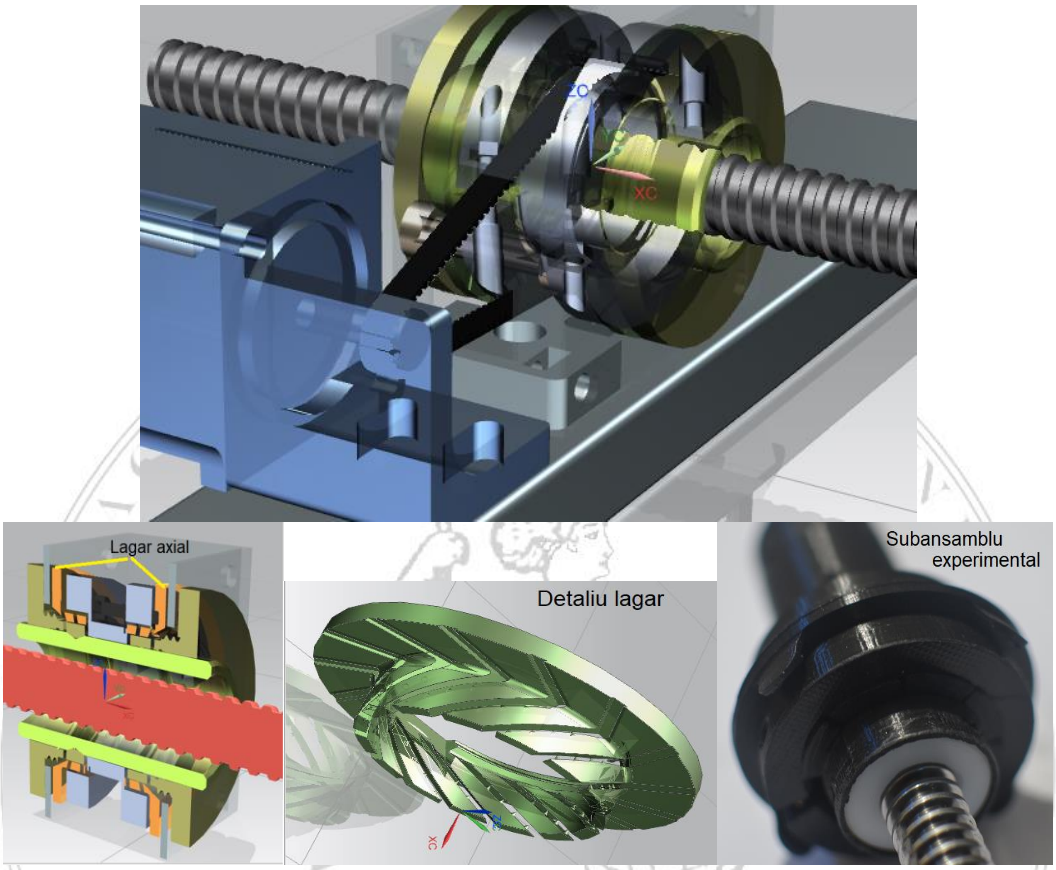

Fig. 5. Drive system with movable nut for fast multi-axis movements.

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