Should We Teach Polymeric Machine Elements as Well?

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Abstract The growing importance and use of polymeric (plastic) parts in many industrial product categories isn't generally accompanied by adequate education at the university level. In response, an overview of relevant literature on polymeric machine elements is presented. Most important differences in characteristics of the polymeric and metallic materials are also highlighted, and the contents of a Croatian textbook on polymeric machine elements are used as a reference.

Keywords Machine element • Polymer • Teaching • Textbook

1 Introduction

Polymeric materials have been produced for more than 100 years. The world production in the year 1900 was 20,000 tons, in 1950 1.7 million tons, in 1990 more than 100 million tons, in 2010 already 265 million tons, and is anticipated to be 300 million tons in 2015 [1]. Constructional thermoplastics including acrylonitrile butadiene styrene (ABS), polyamide (PA), polycarbonate (PC), poly (methyl methacrylate) (PMMA), poly (butylene terephthalate) (PBT), polyoxymethylene (POM), polytetrafluoro-ethylene (PTFE), as well as elastomers (rubber), have adequate properties for use as machine elements. In 2010 the share of constructional thermoplastics used in domains such as building, construction, car industry, electrical wiring, electronics, and home appliances, was 21.5 million tons in the world, of which 2.9 million tons were used in Europe [2]. It is obvious that there is growing application and importance of polymeric parts in many industrial product categories. However, it seems that university curricula don't reflect the quick growing production and usage of products containing polymeric machine elements.

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2 Properties and Suitability of Polymeric Materials for Machine Elements

Taking into consideration that most of engineering curricula are still dealing mostly with metallic materials and their technology, the topics related to polymeric materials are indubitably welcome. It is very important to emphasize that the mechanical properties of polymers are completely different than those of metals. Following can be pointed out [e.g. 3–7]:

(a) Polymers can be extremely extensible and flexible with large elastic deformation. The modulus of elasticity for polymers $E < 7500$ N/mm^2, and for metals is in the range $E \approx 30{,}000 \ldots 210{,}000$ N/mm^2.
(b) Polymers have a tensile strength about 50…100 N/mm^2, i.e. ten times less than steel.
(c) Polymers are roughly five times less dense than metals, but have nearly equivalent strength-to-weight ratio.
(d) Mechanical properties change greatly with variations in temperature. The polymeric materials become brittle at low temperatures.
(e) Polymers creep even at room temperature and polymer machine element under load may, with time, acquire a permanent set.
(f) Water percentage in polymers interferes with their mechanical properties.

Apart from these differences in mechanical properties and some other disadvantages, the following desirable characteristics promote the increasing use of polymeric machine elements:

(a) Polymers are easy to shape.
(b) Polymers can have very good electrical and thermal insulation properties.
(c) Most of the polymers have good chemical resistance.
(d) Sliding without lubrication is possible.
(e) Some of the thermoplastics can be transparent.
(f) Polymers can be coloured throughout.
(g) Possibility to create composites.

The manufacturers are continuously improving the properties of polymeric materials by inventing new materials, mixing different kinds of polymers and applying different additives (e.g. fillers or reinforcements). All this significantly improves the suitability of polymers for use as machine elements.

3 Contents of Standard Textbooks on Machine Elements

Standard textbooks on machine elements typically deal with polymeric parts in following chapters:

(a) Rubber, i.e. elastomeric springs, which are mostly used as supports for compression and shear loads.
(b) Seals for shafts and bearings.
(c) Flexible couplings which can contain elastic parts made of elastomers.
(d) Belt drives, because belts are made mostly of elastomers with polyamid or polyester interior tension chords.
(e) Friction drives that can contain rubber wheels.

Apart from these five cases, some of the most used and well known textbooks in German and English language are dealing with polymers generally and polymeric machine elements to a rather small extent. Here is an overview:

- Niemann, G. (1975, 1983, 1983): *Maschinenelemente – Band I & II & III* [8–10]; design of polymeric parts (1 page), lightweight design (1), polymeric materials (8), polymeric materials for sliding bearings (<1), polymeric gears (12).
- Niemann, G.; Winter, H.; Höhn, B.-R. (2001): *Maschinenelemente – Band 1* [11]; design of polymeric parts (1), lightweight design (1), polymeric materials (6), polymeric sliding bearings (7).
- Shigley, J.E.; Mischke, C.R. (1989): *Mechanical Engineering Design* [12]; polymeric materials (1).
- Steinhilper, W.; Röper, R. (1993, 1994): *Maschinen- und Konstruktionselemente 2 & 3* [13, 14]; welded joints (<1), polymeric materials for sliding bearings (3).
- Hamrock, B.J.; Jacobson, B.; Schmid, S.R. (1999): *Fundamentals of Machine Elements* [3]; polymeric materials (2) + composites (2), snap joints (3).
- Decker, K.-H. (2004): *Decker – Maschinenelemente* [15]; welded joints (2), polymeric sliding bearings (6), design and calculation of polymeric gears (7).
- Wittel, H.; Muhs, D.; Jannasch, D.; Vossiek, J. (2009): *Roloff/Matek – Maschinenelemente* [16]; riveted joints (<1), inserted nuts (<1).

Although the mentioned textbooks have been published over a time span of 34 years, only the books of Niemann [8–11] and Decker [15] pay any substantial attention to polymeric machine elements.

One of the most important and comprehensive books on polymer machine elements has been written in German language by G. Erhard and E. Strickle under the title *Maschinenelemente aus thermoplastischen Kunststoffen* (*Thermoplastic Machine Elements*) and published in two parts in 1974 and 1985 [17, 18]. Practically all machine elements have been elaborated on 460 pages.

The book *Ozubljenja i zupčanici* (*Toothings and Gears*) written by E. Oberšmit [19] has been published in Croatia in 1982. There are 14 pages dealing with the calculation and design of polymeric gears.

The book *Plastzahnräder* (*Plastic Gears*) edited in 1985 by W. Krause [20] gives on 159 pages comprehensive explanations of the calculation, design, control and manufacture of polymeric gears.

4 Contents of Books Dealing with the Manufacturing Process and Design of Polymeric Parts

The books quoted in this chapter are concerned primarily with the manufacturing process for the production of polymeric parts and with the design of polymeric parts generally, not machine elements specifically. However, some of the polymeric machine elements are considered in following books:

- Wimmer, D. (1991): *Kunststoffgerecht konstruieren* [21]; welded joints (18 pages), bonded joints (23), threaded joints (24), press-fit joints (9), snap joints (17), hinges (5), sliding bearings (23), gears (40).
- Erhard, G. (1993): *Konstruieren mit Kunststoffen* [4]; threaded joints (16), snap joints (20), springs (9), sliding bearings (18), gears (32), rollers (15).
- Tres, P.A. (1994): *Designing Plastic Parts for Assembly* [22]; welded joints (48), bonded joints (4), riveted joints (6), press-fit joints (26), snap joints (36), hinges (35).
- Malloy, R.A. (1994): *Plastic Part Design for Injection Molding* [5]; welded joints (32), bonded joints (15), threaded joints (24), press-fit joints (7), snap joints (21).
- Michaeli, W.; Brinkmann, T.; Lessenich-Henkys, V. (Ed.) (1995); *Kunststoff-Bauteile werkstoffgerecht konstruieren* [23]: welded joints (6), threaded joints (13), press-fit joints (6), snap joints (14), hinges (6), gears (13).
- Ehrenstein, G.W. (2002): *Mit Kunststoffen konstruieren* [6]; welded joints (5), bonded joints (9), threaded joints (24), press-fit joints (7), snap joints (11), hinges (2), rolling bearings (2), sliding bearings (14), gears (10), rollers (6).
- Ehrenstein, G.W. (Ed.) (2004): *Handbuch Kunststoff-Verbindungstechnik* [24]; welding and welded joints (190), bonding and bonded joints (88), riveted joints (21), threaded joints (53), press-fit joints (14), snap joints (36), hinges (14).

Although each book covers machine elements to a different extent, these books are very useful help for the design and calculation of some of the polymeric machine elements.

5 Polymeric Machine Elements in University Teaching

To the author's knowledge, with the exception of the Erhard & Strickle's books *Thermoplastic Machine Elements* [17, 18] and Krause's *Plastic Gears* [20], there are no textbooks dealing systematically with such machine elements. This fact, as well as the fact of growing application of polymeric parts in a wide range of industrial products, point to a need of introducing these topics in university textbooks and curricula. That's why the textbook *Polymeric Machine Elements* [7] (266 pages, in Croatian language, written by the author of this paper and co-author R. Basan) has been published at the Faculty of Engineering – University of Rijeka

in Croatia. The content of this book has been chosen by studying previously mentioned books and with the idea that it should be appropriate to the students of undergraduate studies of mechanical engineering. After a short introduction, the book chapters are as follows:

- Properties and types of polymers (15 % of the book content): a short overview of polymers, additives and reinforcements; influential factors for the selection of adequate material; mechanical properties; influences on mechanical properties; friction.
- Joints (45 %): threaded joints, snap joints, bonded joints, welded joints, riveted joints, shaft-hub joints, hinges and springs. Special attention has been paid to threaded and snap joints.
- Bearings (13 %): sliding bearings and (less important) rolling bearings.
- Gears (13 %): the basics of the calculation are as for metallic gears; specific is the control of the tooth deflections.
- Belt drives (3 %): as this kind of transmission is normally presented in standard textbooks on machine elements, only basic explanation are given.
- Wire rope sheaves (2 %): short description.
- Rollers (5 %): although rollers are usually not described in machine elements textbooks, their wide application merited their inclusion.
- Clutches and couplings (4 %): as polymers are widely used in flexible couplings which are always elaborated in standard machine elements textbooks, only some specific polymer clutches and couplings are described.

Lectures on polymeric threaded, snap, and welded joints have already been included in the course "Machine Elements I" at the Faculty of Engineering in Rijeka since 2010. The experience of the author of this paper is that students also sometimes need information about polymeric machine elements when solving problems in other creative study projects and that they usually can't find it in the available literature.

6 Conclusion

Today's designer has the option to choose from a great variety of different polymeric materials because polymers can often compete with other materials such as wood, sheet metal, cast or forged metals, glass, or ceramics. The designer must correlate the end-use performance requirements of the product with the properties and cost of the individual polymeric materials in an attempt to obtain the best material for the application. The designer must also be aware of all advantages as well as limitations of the polymeric machine elements and polymeric products generally in order to perform an optimal job. It is of the outmost importance to make the students of mechanical engineering aware of the differences between the metallic and polymeric materials and the possibilities that afford the use of polymers. One of the important prerequisites for this is introduction of polymeric machine elements in university teaching.

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