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MODERN METHODS OF TEACHING ENGINEERS STUDYING ENVIRONMENTALLY FRIENDLY COMPOSITES

NOWOCZESNE METODY KSZTAŁCENIA INŻYNIERÓW Z ZAKRESU EKOLOGICZNYCH MATERIAŁÓW KOMPOZYTOWYCH

Abstract

This paper explains why and how to teach engineering students studying structural materials obtained from renewable sources. It describes modern approaches in the education of materials science including focussing on design strategies, sustainability and the use of modern educational tools.

Keywords: academic education, sustainability, biobased materials

Streszczenie

W artykule wyjaśniono w jakim celu i jak uczyć przyszłych inżynierów o konstrukcyjnych materiałach pozyskiwanych z odnawialnych surowców. Opisano nowoczesne podejście do nauki o materiałach, uwzględniając proces projektowania i zrównoważony rozwój oraz korzystanie z nowoczesnych narzędzi edukacyjnych.

Słowa kluczowe: edukacja akademicka, zrównoważony rozwój, biopochodne materiały

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1. Introduction

Being used to traditional forms of the teaching of the major material groups (*metals, ceramics and polymers*), academic teachers, and as a consequence, their students and future engineers, often forget or even do not realise that the world of materials science and the materials market is huge, diverse and developing and has much to offer for those who are looking for new solutions that lead to the sustainable development of products and technologies. One of the directions of the current and strong development of materials science is the field of materials obtained fully or partially from renewable sources including engineering structural materials, mainly biocomposites. Although this topic has been explored extensively over the last two decades not just in most academic institutions in Poland, but also by scientists all over the world, it rarely enters the educational and training programs of universities. This, however, is supposed to change in the near future because of the market trends and needs of our society.

At the Institute of Materials Engineering of Cracow University of Technology, new curricula entitled 'Materials made from renewable sources' (comprising teaching materials, draft materials of the curricula, 'master classes' etc.) is being prepared as a part of the project entitled 'Modernisation of two cycles (MA, BA) of competence-based curricula in Material Engineering according to the best experience of Bologna Process', 543994-TEMPUS-1-2013-1-BE-TEMPUS-JPCR ('MMATENG') funded with support from the European Commission. The course is going to be implemented in targeted partner universities in Israel, the Ukraine and Russia in accordance with local requirements and the market [13]. As a renewable source of engineering material, we understand biomass in its various forms as being defined in EU law as 'the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste' [1]. Materials such as natural fibre reinforced composites (NFCs), wood plastic composites (WPCs), polyamides and polyurethanes obtained from plant oils, starch-based and bacterial plastics, polymers and fillers (powders) made from animal shells and many other biomass-based materials already exist out there, not only in the pages of scientific journals but also in the market and in various industry sectors – primarily within the automotive industry, construction, electrical and electronic industries, medicine and sport.

Issues connected to modern educational methods and tools suitable for use in materials science are further discussed in this paper. The authors would like to share their experience and insights gathered from their work on the 'Materials from renewable sources' curricula preparation and implementation as well as their scientific work on biobased materials [6–10].

2. The need for teaching engineers of biobased structural materials

In recent years, new legal, social, environmental and economic aspects (which are all integrally related) of the life cycles of materials and products connected with a broad concept of sustainable development are being considered. This is particularly true for plastics and polymer composites, which form a relatively young and developing group compared to such material groups as metals and metal alloys or ceramics.

In the case of conventional materials obtained from non-renewable sources, several important aspects are raised nowadays that show their weaknesses and motivate us to seek improvements in the following areas:

- the depletion of finite resources (those with a long-term life cycle, including raw materials for metals and most ceramics and petroleum-based polymers) is the most obvious and serious threat. Our dependence on fossil fuels and their rapid consumption especially gives reasons for concern;
- the location of large deposits of non-renewable resources being in countries that are known to be political unstable and of low levels of development may result in rising tensions between the major global consumers and the regions playing the role of the suppliers of raw material – these tensions may easily affect the market;
- recycling is commonly expected to prevent the depletion of natural resources, but this too has some limitations. Loss of quality and material during product usage and recycling needs to be taken into consideration. While for precious metals, recycling can be very effective (high quality and low susceptibility to oxidation), it leads to serious problems in the case of plastics as these are prone to various ageing processes and thermo-oxidative degradation during processing;
- the acquisition and processing of some non-renewable resources is connected with the emission of significant quantities of substances considered as negatively influencing the environment. A common example is the use of fossil fuel-based by-products responsible for the emission of carbon dioxide;
- the degradation of the most non-renewable resource-based materials deposited in the natural environment usually takes a long time. The situation is different with regard to biomass and some biomass-based materials prone to biodegradation and suitable for composting (e.g.: polylactide, thermoplastic starch, natural fibers). This rapid degradation rate is an advantage especially for short-life products, disposable items. This is, however, irrelevant for materials synthesised from renewable sources which are not biodegradable, such as biobased polyethylene for example.

Obviously, these issues listed as the disadvantages of non-renewable sources at the same time show the advantages of renewable sources. However, there are still more reasons why interest in 'green' solutions in fact already exists – these are important more for scientists, designers and manufacturers of a material or a finished product than for standard consumers or for humanity in general:

- eco-politics – legal regulations regarding the use of resources or restrictions of emissions of hazard substances, for packaging, the automotive industry, E&E sectors etc., favour the use of renewable resources and/or biodegradable materials – this is also true when one looks for the possibility to receive funds, realise research projects etc.;
- eco-fashion – green-minded consumers generate a demand for various environmentally friendly products. This has led to the rapid development of 'green marketing';
- rising prices of raw materials resulting in increases in the total material cost.

Even if these points do not convince someone of the importance of biobased materials and the need for their development, the fact is that such new material types are now entering the market with some degree of success (see examples of such commercial biocomposite compounds in Fig. 1). Biocomposites in particular are worthy of inclusion in the academic course on engineering materials as these are gaining serious interest in the biggest industry sectors as structural materials. These materials are gaining prominence during international trade fairs, they receive important awards, find common as well as sophisticated applications in various industry sectors and the most well-known world brands invest in their development; however, many of them are sadly completely unknown to many material engineers, including academic teachers and graduate students.

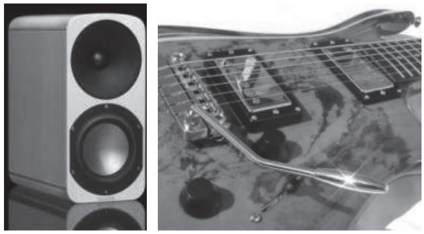
UPM ForMi® – man-made cellulose fibre reinforced plastic composite with a high level of renewable material content (up to 50%)	
Tecnaro Arboform® – made from 100% renewable materials (lignin, natural fibres and additives), Abroblends® (containing biopolymers e.g.: PHA, polyester, Ingeo TM, lignin, starch, cellulose, organic additives, natural resins or waxes and natural reinforcing fibres)	
Kareline® – natural fibre reinforced composite granulates available based on PP, ABS, PS, POM and PLA matrix	
Fibrolon®, FKuR – PP, polyolefine blends or PLA filled with wood flour	

Fig. 1. Examples of ready-to-use biocomposite blends with some potential applications [9]

New standards for biobased and/or biodegradable materials are being developed, especially for biocomposites and biodegradable packaging [4, 5]. Additionally, where novel materials are developed, new terms and definitions are formed which, because of a lack of knowledge, are often misused or misunderstood. For example, it is often believed that the terms ‘biobased’ and ‘biodegradable’ can be used interchangeably to describe the same material, while these features do not always go hand in hand. Such engineering materials as biobased polyethylene, polyamides, polyurethanes and others are not biodegradable and some biodegradable materials are synthesised from fossil fuel feedstock (e.g. polybutylene succinate).

One must remember that it is the new generation of engineers who are, in many cases, expected by their employers to be the individuals who propose new ideas that would increase competitiveness, gain new customers, provide a green corporate image and/or product, and find a promising field for research and development. To help students, academic teachers should provide inspiration by showing recently introduced innovative solutions and motivate them to keep track of such news. To quote well-known research engineer Theodore von Kármán ‘the scientist describes what is; the engineer creates what never was’ [12] it must be clear that honest knowledge on ‘what is’ is not to be underestimated in attempts to ‘create what never was’ – otherwise it may also happen that one preaches to the converted.

3. Approaches towards teaching about materials, design and potential applications

The implementation of a new academic course is always connected with some challenges which need to be addressed. The subject of biobased materials which is discussed in this study is current and developing, designed to keep students up-to-date with important novelties on the materials market. Obviously, to deliver a course on such a topic also requires a teacher to be up-to-date. Information has to be frequently supplemented. In teaching such new and developing materials, one should follow the latest literature, standards and trends in legislation. This need is even more important for courses of biobased materials as topics arise which can be disputable and even controversial – a teacher should prepare themselves to discuss these with students. For example, there are many contentious issues surrounding the use of renewable plant feedstock as a technical material source:

- using land and food crops to produce biopolymers (e.g. to produce thermoplastic starch or polylactide from potatoes, corn or wheat) when there is a global deficiency in food crops;
- overharvesting and genetic modifications of plants in order to obtain useful material properties;
- biomass material inhomogeneity, dependence upon climate, weather conditions, insects and plagues, all of which may result in an unstable supply of plant-based materials.

The task of the teacher here is not only to transfer knowledge but also to provide students with the basis to form their own opinions and reasonably assess facts.

Academic courses on biobased materials should provide students with general information on the materials’ division, applications, advantages and disadvantages. Traditional materials should be described in addition to modern materials which also show some future trends regarding the biomaterials market. It would focus on biopolymers and, even more importantly, biocomposites (the most sophisticated biobased materials nowadays) obtained from different kinds of biomass feedstock. From the course, students should acquire useful knowledge on basic definitions and classifications connected to materials obtained from renewable sources and should also be able to identify the advantages and disadvantages of using renewable and non-renewable sources in the synthesis, processing and use of such materials. There is, however, still more to accomplish with students than that. The goal of courses on materials obtained from renewable sources is to help the students to develop knowledge and skills in the field of environmentally-friendly engineering materials competitive with conventional non-biobased materials. To accomplish this goal, a fresh look at materials science is needed. When introducing novel materials into university curricula, one should take the opportunity to update conventional schemes: the teaching of materials usually starts with their physics and chemistry, structure and general properties, then it covers the most important manufacturing techniques and finishes by presenting a list of some common applications. This is basic and crucial knowledge for material engineers, but there is a lack of discussion on the role of material in the design process, on factors that influence the selection of materials, on the process of the introduction of material to the market, on innovations in this field and on sustainability (these are all connected).

3.1. Material selection in a design process

Teaching students of biobased materials the basic information (definitions, divisions, features etc.) should be supported with examples and exercises on its practical use in the designing process – this is much more efficient in showing the feasibility of the use of such materials than a list of properties or pros and cons. A task that requires students to look for proper material/materials for a specific application by comparing availability, prices, processing, selected phisico-chemical properties among other factors (see section 3.2 on sustainability) and justify their choice is a good idea. However, it remains important to specify what the place of material selection is in the design process. Is a given material of the product a consequence of the chosen shape, processing, function etc.? Or may it be the other way around? The first strategy is more common, but the other is also used and it is called ‘design for materials’ or ‘materials driven design’ [15]. ‘Materials driven design is all about bringing materials at the beginning of the design process (even before deciding on the function and shape of the product or its manufacturing method). This can be by using material samples to broaden the idea generation or by using a single material as a starting point to explore possible applications’ [17]. This kind of design process is important for innovative materials without an established position in the market as well as for the purposes of green marketing. Biocomposites, primarily those filled with wood flour/chips or natural fibres, are well suited to the purpose of materials driven design having an interesting ‘eco-appearance’ and textures. Let us take the polymer composites in general and NFCs in particular as an example. They have low densities and thus, their specific tensile properties are very interesting compared to other engineering materials. In fact, many NFCs show similar or even better specific properties compared to some metals and their alloys or glass-fibre reinforced composites. This encouraged car part manufacturers looking for ‘green’ light-weight solutions to redesign some car panels and to adapt them for production with the use of biocomposites.

The possibility of finding new applications for old materials is also inspiring and worth mentioning. Wood and natural fibres, being traditional materials, are undergoing a revival again and are being applied in new forms in technical applications. Some traditional and newer applications of natural fibres are presented in Fig. 2.

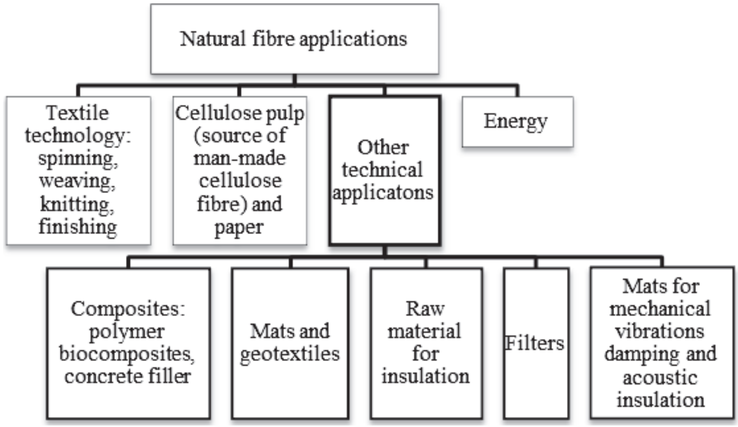


Fig. 2. Applications of natural fibres [9]

Wood is also applied in new forms, for example, as a filler of thermoplastic composites (WPC) or as a fibrous material for isolation. Another example is CLT (cross laminated timber) used to built a wind turbine in Hannover (Fig. 3).

Fig. 3. CLT wind turbine in Hannover (Timber Tower Research Project) [9]

3.2. Sustainability

A lot of scientists working on biobased materials who publish their journal papers tend to emphasise the advantages of such materials, write of their bright future and explain their superiority over the materials obtained from non-renewable feedstock – companies advertising their green products on their websites and during trade fares do just the same. Their purpose is to promote these materials rather than to give cool judgments on them; this is understandable. However, this strategy is not the best one for teaching future engineers. Is it our purpose to compliment biobased materials and deplore non-renewable materials in the eyes of our students? Can we declare that these materials are, in general, 'better' or 'worse' than materials based on non-renewable feedstock? It is preferable to make students consider when a given material may be beneficial for a clearly specified product whilst taking various factors into consideration. Students should evaluate when to use one material over and above another, or even more importantly, explain the complexity of this choice and provide accessible tools that can be used to make the decision less complex. In fact, this is the question of what can be called sustainable and on what basis.

Sustainability should be considered as an integral part of the design process among all engineering students [11]. The World Commission on Environment and Development defines sustainability as meeting the needs of the present without compromising the ability of future generations to meet their own needs. According to the Union of Conservation Scientists (IUCN), the United Nations Environment Programme (UNEP) and the Worldwide Fund for Nature (WWF), sustainability is improving the quality of human life while living within the carrying capacity of the Earth's supporting eco-systems.

In general, what we are trying to accomplish in sustainable development is meeting the functional and hedonic needs of certain groups of customers as well as the minimisation of hazardous emissions, energy and material consumption or land use. Clearly, the assessment of product sustainability is not a simple task and it requires deep analysis of various aspects connected to all the stages of the life cycle of a product. In general, these aspects include: raw sources and their acquisition, manufacturing and product use, and, finally, waste management. A useful tool that can be applied here is a life cycle assessment (LCA). LCA is one of several environmental management techniques that are used to study the environmental aspects and potential impact on the environment connected to a given product or material. The technique has been performed mainly on engineering materials and products since the nineteen-nineties.

It is a good idea to not just present it to students, but also, to make them realise its limitations. Often, LCA does not consider real-world infrastructure and costs which fluctuate. For example, in the plastics industry, price changes tend to determine whether oil-based or natural-gas-based feedstock is used in polyolefin production. The prices of natural fibres, as another example, depend on their quality, which is related to their growing conditions. Furthermore, LCA generally do not consider the availability, consistency, and stability of the various raw sources under consideration. Even if an LCA indicates a certain biopolymer as the most sustainable choice for a product, its use may not be possible at the required quantities. Another issue which is not taken into consideration in LCA is the consumers' willingness or unwillingness to pay more for what is found to be a lower-impact product. In many cases, there is also difficulty in defining what level of emissions or waste is acceptably sustainable for a given type of product [16].

Sometimes, a variety of factors, including those mentioned above, may be the source of serious disagreement, conflicts and accusations between the authors of different LCA reports on the same material, product or process, especially if the results of the analysis have a negative effect on a certain company or industry sector, for example, [2]. Prof. Ramani Narayan, working on developing the LCA method said in one of the interviews that '...LCA shines a spotlight on a single product and identifies the areas where it could/should be improved... However, LCA's are increasingly used as a comparative marketing tool using, for example, selecting parameters and impact categories favourable to one's product, which cannot and should not be the intent of an LCA.' [3].

By preparing a task with different scenarios for simple LCA analysis of selected biobased and non-biobased materials, a teacher can make the student realise the need for its responsible and careful use.

3.3. Thinking regionally

'Thinking regionally', defined here as using native, regional resources in materials and product manufacturing processes is actually connected to 'thinking sustainably'. This concept assumes economic and environmental benefits for both the manufacturer and for the region itself taken from savings on the transportation of the resources and on building competitiveness. To promote this idea among students, one should motivate them to look for possibilities to manufacture green products that take advantage of the following local factors:

- the cultivation of plants which can be used to produce biopolymers or as components of biocomposites – especially those specific for a region because of climate, soil etc.;
- the existence of chemical industry involved in the production of biobased materials or interested in sustainable development;
- the existence of manufacturers of products made with biopolymers, biocomposites and other biobased materials.

Students may analyse global and local market potential focusing on materials and products that exist on the market and that use market projections.

3.4. The diversity of materials and the force of habits

To be truly honest with the students about the process of material selection or finding applications for materials, one should make them realise that usually, when a manufacturer look for the possible improvements in his products portfolio, a change in the type of material used is less common than changes made in the manufacturing process and/or geometry of the product. This is especially true with regard to switches from traditional materials into more innovative materials – the consequences of such a decision may be very complex. Force of habit also plays an important role here. For traditional materials, methods of manufacturing and the consequences of their application are generally known; however, for new materials, what is unknown seems suspicious and difficult. The variety of engineering materials present on the market within different material groups is huge, as is the competition among them.

4. Modern tools in the teaching of innovative materials

In educating about materials which are developing every day, the use of modern educational tools accompanying traditional ways of teaching (known as 'b-learning' or 'blended learning') should enable them, in a motivating and inspiring manner, to responsibly seek and use different sources of knowledge and to apply that knowledge to solving real-life problems.

These modern educational tools generally require access to the Internet and certain software with the use of a desktop computer or a personal electronic device (in the case of m-learning [mobile learning]). When designing e-learning and m-learning courses, the teacher has numerous possibilities to provide students with access to knowledge and important data, as well as to develop their skills. Some examples are given below which focus on the needs of education in the field of materials science and biobased materials:

– material databases – there are many material databases accessible on-line. Some of these require payment and some are free of charge. The 'Materials Data Center' offers a free biopolymer database which can be successfully used during work with students, e.g. for an exercise on the selection of materials;
– news from the market – important sources useful in teaching about innovative materials include trade journals and websites (e.g. www.news.bio-based.eu, www.compositesworld.com, www.en.european-bioplastics.org, www.bc.bangor.ac.uk) as well as market reports. To supplement this information, it is useful to enable students to take part in trade fares connected with the course when such opportunities arise;
– scientific publications – full-text databases including the university repository should be used as a source of current journal papers or textbooks (many books on biocomposites and other materials from renewable sources are available via the Knovel database);
– computer software – for the purpose of the academic course on biocomposites and other biobased materials, the use of software dedicated for life cycle assessment would be most beneficial as it would help students to identify various factors affecting material selection and connected to sustainable development as well as to observe some of the limitations of LCA method;
– online lectures and other educational films, animations, audio recordings or virtual laboratories – using e-learning platforms, teachers may direct students towards useful sources;
– self-prepared, interactive educational materials – including recorded lectures, textbooks, but also virtual labs – these are useful for teaching about the properties of biobased materials which are less accessible and often more expensive than materials usually used for the preparation of specimens for conventional laboratory work. It is also possible for a teacher to prepare smartphone applications, for example, in the form of quiz or a simple game (a lot of tutorials that demonstrate how to accomplish this are easy to access on the Internet) [14].

Using a Moodle e-learning platform, a teacher can share information with students and redirect them to useful websites, prepare and evaluate tasks, provide feedback and grades, and communicate with student in various ways.

5. Conclusions

Materials obtained fully or partially from renewable sources, especially those suitable for technical applications like biocomposites (mainly wood plastic composites and natural fibre composites) are becoming more and more important on the materials market. They are competitive options in comparison with commonly used materials obtained from non-renewable feedstock – mainly with conventional plastics and polymer-matrix composites. They have been intensively tested for over two decades and they are now a part of the portfolios of the biggest chemical producers as well as smaller companies all over the world. There is a need to introduce these materials into the university curricula and the opportunity to make it in active learning environment using various verified up-to-date online sources of knowledge and tools which make learning more interesting and more accessible.

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