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STRUCTURAL MATERIALS IN AGRICULTURAL MACHINES

Summary

The paper presents directions for the development of basic structural materials used in agricultural machines. A review of major achievements in materials engineering in the development of novel structural materials and upgrading existing ones is presented.
***Key words**: structural materials, agricultural machines, development, nanomaterials, polymers, composites*

MATERIAŁY KONSTRUKCYJNE W MASZYNACH ROLNICZYCH

Summary

W pracy przedstawiono kierunki rozwoju podstawowych materiałów konstrukcyjnych stosowanych w budowie maszyn rolniczych. Ponadto dokonano przeglądu najważniejszych osiągnięć inżynierii materiałowej w zakresie tworzenia nowych materiałów konstrukcyjnych i nadawania już istniejącym coraz lepszych właściwości.
***Słowa kluczowe**: materiały konstrukcyjne, maszyny rolnicze, rozwój, nanomateriały, polimery, kompozyty*

1. Introduction

It is the mission of science to generate progress and development in all areas, particularly in the case of applied sciences. Biosystem engineering, including agricultural engineering, covers technical objects used on biosystems, among which the most numerous group is composed of agricultural machines. History clearly shows their importance in the development of our civilization. The use of machines has made it possible to increase the volume of agricultural production and satisfy growing demand for food. Development of this sector is facilitated by the application of research results provided e.g. by scientists specializing in agricultural engineering. Such research results have been discussed in numerous publications, presenting various achievements as well as implementation of research in the manufacture of agricultural machines. Broadly understood development of agricultural machines is a function of progress in several areas, including:

– original, pioneering structural solutions,
– technological and organizational changes in machine operation processes,
– computerization and electronification of machine control processes,
– implementation of novel structural materials.

The primary aim of this paper is to present a review of selected structural materials as a source of technical progress in the design of agricultural machines. An incentive for undertaking this subject was connected with the advances in materials engineering, including the development of novel materials and upgrading existing materials. Technologies of their manufacture are being improved, e.g. continuous casting of steel, rotational moulding of plastics, etc. [15]. All these factors affect various aspects of our activity. The term material is ambiguous and it generally refers to the object used in the production process. In the analyzed case they will be materials introduced to the manufacture of agricultural machines, i.e. structural materials.

For centuries the function served by materials has not been fully acknowledged. Humans used only the materials provided by nature, such as wood, stone, animal hides and bones, etc. Causes for such a situation has been humourously attributed to the tradition of ancient Greece. The ugly and lame god Hephaestus, who was working on materials, was an exception among the beautiful Olympians. His appearance showed that working on materials was not truly appreciated. Other types of activity represented by the beautiful gods, e.g. Eros and Dionysus, were connected with continuous development in human history. The traditional teaching of history linked the role of materials in the development of civilization by defining its individual epochs using names of materials commonly used in those times to produce tools, thus coining the terms the Stone Age, the Bronze Age and the Iron Age. It was late as mid-19^{th} century that materials were shown to be the basis for further progress [4, 5].

2. Structural materials

The world around us is material, being composed of matter. In turn, a structural material is such a solid, whose properties make it useful for humans when used in the form of tools produced from it. Tools and later also machines have made it possible to multiply the strength and functionality of human hands. The application of silicon as a material has upgraded for the first time in human history the power and functionality of the human mind and this is where the huge potential for its development may be found.

The first materials used in agriculture initially included stone and - starting from ca. 6 000 B.C. - ceramic products from burned clay. Bronze was first produced around 3 500 B.C. and iron around 1 400 B.C. Bronze was not used to produce agricultural tools due to its high price and low mechanical strength. In turn, production of iron or rather steel required knowledge how to control the process of its casting and to obtain material with repeatable properties. Steel was produced e.g. in the Staropolskie Zagłębie [The Old Polish Industrial Region] in the Świętokrzyskie province in bloomeries; however, the material was of poor quality. In Damascus the manufactured steel had excellent properties, but it was not fully clear at that time why it was so good. Now we know that it was a consequence of large amounts of manganese in the used high quality ore. Only in 1799 it was discovered that steel is an alloy of iron with carbon and its content has a significant effect on properties of steel. Next the positive effect of other alloy additions was identified [3]. Thanks to the inventions of Siemens, Marten and others steel of repeatable and increasingly better properties was produced in large amounts and at low cost. In that period the first efficient and durable agricultural machines started to be produced thanks to the availability of a good and relatively cheap material – steel. It was enough to use steel in the production of tools and machines previously made from wood (ards, windmills, water wheels) to increase greatly their efficiency, functionality and to inspire new ideas.

Plastics, called polymers, started to be produced on a mass scale in the second half of the 20th century as substitutes of metals and their alloys. It soon turned out that they are valuable structural materials, which share in machine designs has been growing dynamically. They are organic high molecular weight compounds, with carbon being their primary component. They are characterized by good strength properties, chemical resistance, low density and formability, while they are also heat and electricity insulators. They are typically non-toxic and physiologically neutral [8]. However, they have several drawbacks, such as working temperature, poor biodegradability and high price [14].

Composites are structural materials of the future, not only in machine design. An inspiration for their development was provided by wood – a natural composite. By combining various materials it is attempted to eliminate disadvantages of each individual material and to enhance their advantages. It consists in the use of thin, flabby fibres, which are typically made rigid using a polymer matrix. Initially glass fibre was used, later to be replaced by Kevlar and carbon fibres [19]. This provides an elastic, durable and light material. Such material is used e.g. to produce blades of wind turbines.

Machine parts working in soil require materials of high resistance to abrasive wear. In this respect ceramic materials are considered to be very promising. Their limited strength to dynamic loading is currently an unsolved problem [2].

Similarly as other sciences, materials engineering uses biomimetics (from Greek *mimesis* – to imitate and *bios* – life), i.e. observing nature, which is difficult even with advanced apparatus. An example may be provided by spider web, several dozen times thinner than human hair, enduring proportionally high loads. Technologists intend to develop an industrial production process for such a material, although it has not been completely successful as yet.

3. New structural materials

Designers and producers of agricultural machines have successfully used novel structural materials. The greatest changes have been associated with an extensive application of plastics [1]. The degree of their incorporation into the design of various machines depends on their type. The most profound changes and thus the resulting progress have been observed in the case of sprayers. Very expensive tanks and fixtures, previously made from copper alloys, are currently manufactured from plastics. This material facilitates application of simpler and easier production technologies. The technology of rotational moulding applied in the manufacture of plastic sprayer tanks provides high-capacity tanks, of optimal shapes at low production costs, while facilitating at the same time the introduction of upgrades. Plastics are materials of other sprayer parts, such as nozzles, valves, filters, pump parts, etc. The simple manufacturing technology provides a broad assortment of nozzles. Their application makes it possible to considerably increase spraying efficiency and reduce environmental hazards.

Similarly as in the case of sprayers, plastics have facilitated huge progress in irrigation equipment. Sprinklers, pipelines and other fittings are typically produced from these materials. Plastics are also used to manufacture various tanks, including tractor fuel tanks, shields, mudguards, as well as gear wheels, slide bearing liners, etc. Parts made of plastics are corrosion resistant, which enhances their durability and eliminates the need to apply anticorrosive measures. Density of plastics is on average approx. $1 g \cdot cm^{-2}$ and thus parts are 7- to 8-fold lighter than their equivalents made of steel, they may be easily regenerated e.g. by glueing [6]. Reduced weight of component parts, particularly for mobile machines, such as most agricultural machines, ensures tangible savings in their operation. Examples may include modern trailer sprayers, for which in the function of production period their unit weight decreases in relation to working width and tank capacity. Table 1 presents example information on the effect of novel structural materials on selected parameters of trailer sprayers.

At present anticorrosive protection and self-loosening safeguards are made of plastics. This eliminates the need for commonly used cotter pins, washers and other self-loosening prevention measures.

Parts for prototypes of new machines may be made using 3D printers. This facilitates intensification of implementation work and increases the number of tested solutions.

Table 1. Changes in selected parameters of trailer sprayers in the function of the year of their production
Tab. 1. Zmiany wybranych wskaźników opryskiwaczy ciągnikowych w funkcji roku ich produkcji

Year of the production	Working width *b* [m]	Tank capacity *v* [l]	Empty weight *m* [kg]	$\frac{m}{b}$ $[kg \cdot m^{-1}]$	$\frac{v}{m}$ $[l \cdot kg^{-1}]$
1998	12	400	200	16.60	2.00
2014	12	400	180	12.00	2.22
2005	12	400	165	13.75	2.42

Source: the authors' study / Źródło: badania własne

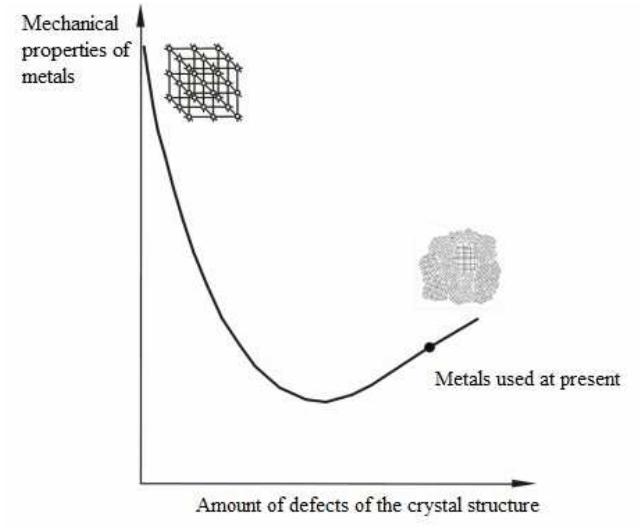
Considerable problems are connected with abrasion wear of machine parts working in soil. They cause deformation of their shape and an increase of the nose radius, thus deteriorating their functional characteristics and increasing their working resistance. Novel types of steel and other materials with better properties are being searched for to ensure their enhanced durability under these adverse conditions. An example may be provided by tool tips of tungsten carbide used for these parts by Vaderstad Marathon. According to the manufacturer's data their durability is approx. 7-fold greater than those of conventional steel parts. A study by [11] presents results of tests on the application of Cr-Ni-Mo duplex steel with an addition of nitrogen and adequate heat treatment on parts working in soil. The authors definitely stated that this material may successfully replace forged and rolled steel parts working in soil, at the same time providing them with greater durability. Cast materials, thanks to their simpler manufacturing technology in comparison to plastic forming, are interesting options for the manufacture of various parts of agricultural machines [12].

Advances in the production of metallurgical products are connected with the introduction of the so-called structural steel closed sections. They have replaced e.g. angle sections, U-iron and T-bar sections, previously used to manufacture frames of agricultural machines. As a result, thanks to their more advantageous strength properties the weight of machines could be reduced (table 2). An additional advantage of their application is connected with an increase in corrosion resistance of machine structures.

4. Directions for development of structural materials

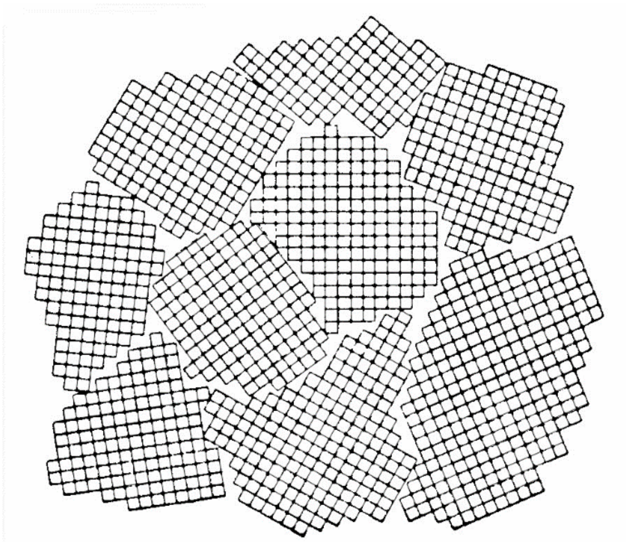
Considerable potential for development is provided by structural materials also in the case of agricultural machines. In the microscale metals and their alloys as well as plastics and composites differ in their crystalline structure. Hardening and cold work, commonly used to improve mechanical properties of steel, reduce its crystallinity. However, it is commonly known that strength parameters as well as physical and mechanical properties increase with an increase of crystallinity. These dependencies are presented in Fig. 1.

A serious problem is connected with a lack of a cheap production technology for materials with greater crystallinity. Losses in transmission of electrical energy result from low conductivity of the material used in transmission lines, resulting from their granular structure (Fig. 2).



Source: the authors' study / Źródło: badania własne

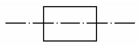
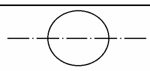
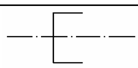
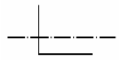
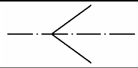
Fig. 1. Mechanical proprieties of metals as the function of rupture of the crystal structure
Rys. 1. Właściwości mechaniczne jako funkcja zburzenia struktury krystalicznej



Source: the authors' study / Źródło: badania własne

Fig. 2. Grain structure of metals
Rys. 2. Ziarnista budowa metali

Table 2. Cross-breaking strength of selected steel sections as the function of the shape of their cross section
Tab. 2. Wytrzymałość na zginanie wybranych materiałów hutniczych jako funkcja kształtu ich przekroju poprzecznego

Parameter					
Symbol [mm]	64 x 3	Ø 60 x 4	50 x 38 x 5	60 x 60 x 6	60 x 60 x 6
Cross section area A [cm^2]	7.03	7.07	7.12	6.91	6.91
Cross-breaking strength W_x [cm^3]	13.27	9.34	10.06	5.29	8.52
Weight / Unit length [kg/m]	5.52	5.03	5.59	5.42	5.42
Bending strength of section / Bending strength of pipe [%]	142%	100%	108%	57%	91%

Source: the authors' study / Źródło: badania własne

The theory of electrical conductivity for metallic layers proposed by Sommerfeld and Lorentz describes this phenomenon as scatter of electrons on foreign admixtures, interfaces and defects of the crystal structure of solid metal solutions [7]. It results from the above that subtle changes in the material microstructure are sometimes required to modify (improve) properties of these materials. Properties of structural materials are to a considerable extent determined by their microstructure, which should be free from any structural defects and should exhibit resistance to the formation and spread of microcracks [10].

In this area considerable potential applicability is facilitated by nanotechnology, i.e. the concept of a molecular assembler, using which a desirable microstructure may be arranged from single atoms and molecules, and in this way mechanical properties of the material are changed. Theoretically we know how it can be done and we may do it in a laboratory. We need to have an adequate technology to apply it on a commercial scale [9, 17].

Combustion engines, whose watt-hour efficiency is 20-30%, are primary sources of mechanical energy in mobile agricultural machines. At the same time approx. 30% of thermal energy generated by combustion of fuel is absorbed and scattered by the cooling system in order to balance and lower the temperature of engine parts so that materials used in their structure are not destroyed [13, 16]. From the point of view of thermodynamics an engine may work at a much higher temperature and then its watt-hour efficiency increases. We need only adequate materials, which may work under such temperatures.

An important role in renewable power engineering is played by photovoltaic cells. Currently constructed panels are composed of semi-conductors (silicon, germanium) and have the watt-hour efficiency of approx. 14%. A problem is also connected with their complicated production process, high unit weight and problematic waste disposal. A breakthrough in this area may be provided by perovskite cells. Perovskite as a mineral is found in nature, while it may also be produced in chemical processes. Its crystal structure makes it possible to reach a 20% watt-hour efficiency and theoretically even 30% by perovskite-based cells. An additional advantage is associated with the simple manufacturing technology of such photovoltaic cells at ambient temperatures, even in the form of sprayed film [18].

An interesting option is provided by neodymium magnets produced using a lathanide element called neodymium. It is obtained by sintering with powders of other metals. Thus produced magnets have a very strong magnetic field. A measure of its value may be shown by the fact that a magnet may hold a weight approx. 1300 times greater than its own weight. They may be used to improve watt-hour efficiency of electrical machines. This will revolutionize the fastening technology also in agricultural machines.

5. Concluding remarks

The conducted review of selected structural materials, their properties and applications makes it possible to formulate certain generalizations, which may be presented in the form of several conclusions:

1. Agriculture and more generally biotechnological processes, impose particularly difficult requirements in relation to technical objects involved in their performance. This pertains to highly variable loads, corrosion resistance, low mass density, biological neutrality, easy biodegradation, etc. These problems may be solved using appropriate materials.
2. New materials offer not only solutions to these problems, but also new areas for development. In many cases these materials make it possible to apply simpler and thus cheaper manufacturing and servicing technologies for technical objects. They facilitate improvement of many quality indexes of their operation, at the same time making these technical objects more ergonomic and safer.
3. Materials engineering and producers of structural materials perceive the specific character of technical objects in bioengineering and attempts to meet its requirements. The final solution should be provided by the cooperation of specialists in materials engineering and bioengineering at the design stage of technical objects for this sector, in which case effects measured by many criteria will be the best.

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