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Utilisation of industrial steel wastes in polymer composite design and its agricultural applications

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Abstract. A constant development of agricultural activities is linked inherently to generation of significant amount of chemically aggressive organic wastes. This paper outlines a synergistic opportunity for industrial metalworking and plastic wastes recovery and re-use, with clear final product – composite steel-polymer material. Experimentally obtained composite polypropylene-perforated steel material is characterized by structural strength and stiffness provided by perforated steel tapes, and corrosion resistance assured by polypropylene layers, which protect steel from aggressive environment. Authors suppose that waste-based composite material could be applied for certain agricultural constructions, and namely, for boundary construction of farm animal feed lines and storage facilities for organic wastes and minerals.

Key words: perforated steel material, industrial wastes, polymer composites, cellular structures, feed lines, waste storage.

INTRODUCTION

A constant development of agricultural activities is linked inherently to generation of significant amount of chemically aggressive organic wastes. Often, such chemical activity is quite harmful causing an accelerated corrosion of bearing structures, which in turn creates serious problems for waste storage and treatment. An estimate of losses related to facility corrosion is 5–10% percent of new equipment.

Circular economy assumes a resource-closed-circuit utilization oriented economy (Yin, 2011), therefore a proper recycling of industrial steel wastes for new composite materials development is in-line with modern tendencies for resource-efficient European economies. A large part of the industrial wastes composed of metallic and plastic materials. Here, one of the most interesting steel materials with great potential for use in construction and design applications are perforated steel tapes (or bands), obtaining from stamping operations in metalworking industry. At the same time, one of the largest plastic residue groups composed of polypropylenes (around 20% of all waste plastic materials) (Lisicins et al., 2015). As an example of perforated steel materials in construction can be mentioned a thin-walled cement composites. There the perforated steel wastes reinforcement performs the function of reinforcement in Portland cement-based matrix (Skudra & Skudra, 1999). The reinforcement of plastics with different metallic materials was also studied (Skudra, 1975).

In current paper, a composite material based on combination of polymer (polypropylene) and perforated steel waste materials for agricultural applications is proposed. Thus, contributing to the two large groups industrial waste materials efficient recycling for new construction materials design.

Agricultural structures suffer of the of corrosion destructive effects due to moisture content, chemicals, animal respiration, and especially fertilisers (Oki & Anawe, 2015), causing deterioration of walls and ceilings (Tubens & Brongers, 2001). Certain fertilisers are more corrosive reacting with other substances and producing aggressive gases (ammonia or hydrogen sulphide). For example, ammonium nitrate can lead to increased corrosion via hydrolysis to acids. Hygroscopic properties of many fertiliser powders are leading to corrosion due to reaction with moisture.

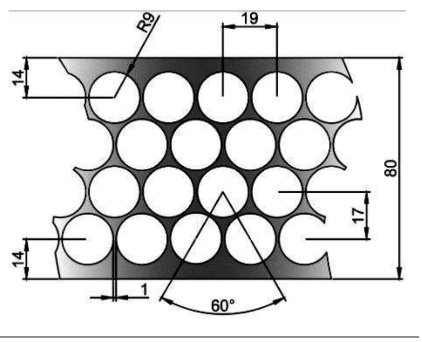
Most frequently applied metallic materials in agriculture are: mild steel, aluminium, galvanized steel. Mild steel is often used to contain fertilisers because it is cheap, but adequate surface cleaning, preparation and coating are necessary. The main disadvantage in this case is that regular usage of additional protective chemicals can be costly. As an alternative of carbon steel galvanized steel and stainless steel can be used for agricultural constructions. Stainless steel structures my cost 5-10 time more comparing to mild steel analogues. At the same time zinc plates mild steel rises final costs up to 25–30% (Roymech.co.uk n.d.).

MATERIALS AND METHODS

In a framework of current paper, we offer a look at another alternative solution based on industrial wastes recycling for manufacturing of composite material suitable for agricultural construction and adjacent applications. That is a composite material based on carbon steel perforated bands (types or sheets) incorporated into polymer matrix (polypropylene or polyethylene). It is important to notice that for raw materials of both components of the composite residual (wastes) materials can be used. Perforated steel tape used in experiments is a residual material obtained from the punching process during the manufacturing of driving chain elements. Suggested material (Table 1) is characterized by good mechanical properties and moderate costs, which is about 1/3 of the price of solid steel material.

Table 1. Properties of sample perforated steel used in experimental works (PST-4)

Steel	08пс-ОМ-Т-2-К (according to GOST 503-81)
Thickness, mm	1.25
Width, mm	93
Permeable area, %	66.97
Effective cross-sectional area, mm^2	16.14
Tensile load bearing capacity, N	4,108.27
Tensile strength, N mm^{-2}	318.22
Displacement, mm	3.27
Strain, %	1.78



Waste materials re-use efficiency is strongly related to physical and mechanical properties and materials geometry. Mechanical properties are important for load-bearing elements and constructions manufacturing, but geometrical for decorative and non-structural materials design. The most common types of polymers used in the EU is polyethylene and polypropylene, amounting to almost 55% of polymers used in various technological processes (Plastics Europe 2015). Polyethylene and polypropylene wastes have very long period of decomposition, that is important to pay more attention to polyethylene and polypropylene waste materials re-use. Polymer material residues can be combined with perforated steel material wastes, creating new composite materials suitable for construction industry. Polyethylene and polypropylene possess good weldability that allows fast and convenient materials joining for different types of structures. In present study, we have used a polypropylene as a raw material, which properties are presented in (Table 2).

Table 2. Properties of polypropylene used in composite material design

Density, g cm^{-3}	0.91
Modulus of elasticity, N mm^{-2}	1,300
Tensile strength, N mm^{-2}	32.00
Breaking extension, %	> 50
Melting point, °C	162–167

Joining of metallic and polymer materials is a difficult issue (Ochoa-Putman & Vaidya 2011). Perforated steel band has an advantage thanks to perforation slots, allowing the melted polymer to flow through the openings and ensuring mutual adhesion. There are several methods for producing of presented composite material. Main on them are pultrusion, hot pressing and polymer injection.

Hot pressing. Extrusion billet (sandwich type) heated between the press plates with a predetermined load. Disadvantage: use of template system, load, temperature parameters must be precisely defined in order to obtain the desired shape component. Advantages: The process is fast, cheap and handy for making prototypes.

RESULTS AND DISCUSSION

In current experimental research, the composite material was produced by means of hot pressing process, using steel parts made of steel tape PST-4 sample (Fig. 1).

Figure 1. A composite polypropylene-perforated steel material – plane element.

Mechanical characteristics of obtained polymer-metal composite samples (a set of 5 trials) are shown in (Table 3).

Table 3. Mechanical characteristics of the polymer-metal composite on the basis of PST-4 sample

Parameter	Mean value
Maximum axial tensile load, kN	21.64 ± 0.54
Tensile stress, N mm^{-2}	39.28 ± 0.69
Strain, %	4.14 ± 0.22
Elastic modulus, GPa	3.38 ± 0.17

Possible applications of obtained composite material are based on structural elements that can be produced using a ready-for-use components. Our solution offers an application of pre-made composite elements, such as rigid L and I shape profiles (Fig. 2, a, b, c) and reinforced composite plates to produce quickly mountable and sustainable structures protected from corrosion (Fig. 2, d, e).

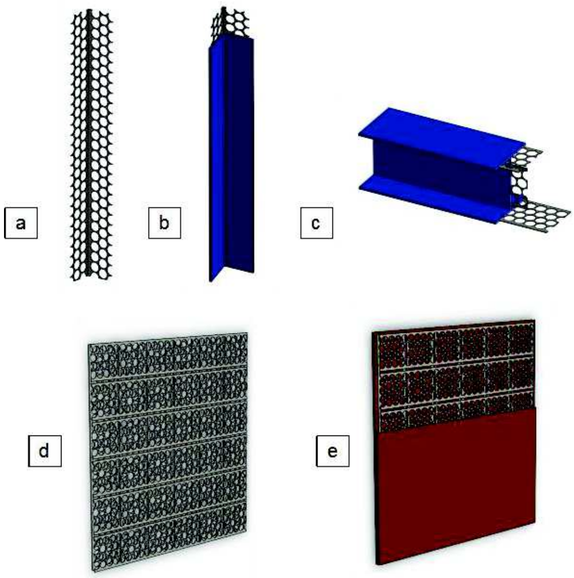


Figure 2. Perforated steel L and I shape profiles (a, b, c) and structures (d, e).

Table 4. Main benefits and disadvantages of proposed constructions

Benefits	Disadvantages
Cheap raw materials for visually appealing structures	Less corrosion resistance than in case of stainless steel
Possible use waste materials (steel types and discarded polymers)	When using waste requires proper selection of raw materials
Fast assembling and dissembling	Time-consuming production of materials
Lightweight and rigid structure with need for regular anti-corrosion post-processing	Difficult to control the potential corrosion of steel

For a number of cases the proposed solution may prove more effective, than for traditional materials. For example, if it is necessary to build a durable structure, composites walls will lasts longer than walls made of steel, meanwhile composite structures will cost less than similar structures made of galvanized or stainless steels. The following (Table 4) summarizes advantages and disadvantages of proposed solution.

CONCLUSIONS

1. The present paper suggests a new composite material for protection of agricultural facilities against destructive effects of corrosion and based on recycled industrial wastes – perforated steel wastes and polypropylene.

2. Thanks to its mechanical properties (axial tensile load and elastic modulus), the suggested material could be used for agricultural facilities construction and repair.

3. Applications advantages of the offered material outbalance its possible limitations by following characteristics:

- corrosion resistance,
- lightweight and rigidity,
- visual appealing,
- fast assembling and dissembling.

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