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Influences of the circular economy in industrial engineering

C Botezatu, B Oroian, A Hrituc and I Condrea

“Gheorghe Asachi” Technical University of Iasi, Faculty of Machine Manufacturing and Industrial Management, Department of Machine Manufacturing Technology, blvd. D. Mangeron, 59A, 700050 Iasi, Romania

E-mail: carmenvioletabotezatu@gmail.com

Abstract. Epoxy resins are some of the best-performing resins currently available on the industrial market. By adding additional filler materials (glass, porcelain), the epoxy resin acquires superior mechanic and thermal properties. The areas in which epoxy resins are used are multiple: metal coating, electronics and electrotechnics, manufacture of paints and adhesives, obtaining plastics with special properties or in construction. Epoxy paints are used indoors because they are UV-sensitive (they get the appearance of chalk) on the outside. However, they are very good as corrosion-resistant primer and very good protection against water and humidity. That is why they are used as a first layer in the automotive or shipbuilding industry. Epoxy adhesives are very resistant and are used in many areas: airplane, car, bicycle construction. Therefore, when making the frame to pour a resin, it should be taken into account that there are few materials that do not stick very well.

1. Introduction

The circular economic model is based on the reuse, repair and recycling of materials and products. The objectives of such an economic model are increasing resource productivity and separating economic growth from resource consumption and environmental impact, [1].

Circular economy is a generic term used for an industrial economy that is created to be restorative and where the material cycle is of two kinds: the biological cycle, where processes act so that the components revert to the biosphere without any negative effects; the second cycle is the technical one where the components are used very efficiently and do not enter the biosphere, [2].

The circular economy deviates from the traditional, linear economic model, which is based on a take-to-eat-throw pattern. This model is based on large amounts of cheap, easily accessible materials and energy. Also, part of this model is wearing planning - designing a product to have a limited lifetime to encourage consumers to buy a new one.

Why do we need to move to a circular economy? World population is rising, so does demand for raw materials. However, the supply of critical raw materials is limited. Finished supplies mean that some EU countries depend on other raw materials countries. In addition, the extraction and use of raw materials have a major impact on the environment. They also increase energy consumption and CO₂ emissions. Smarter use of raw materials can reduce CO₂ emissions, [3].

What are the benefits? Measures such as waste prevention, eco-design, and re-use could save 600 billion euros in EU companies - equivalent to 8% of annual turnover - while reducing total greenhouse gas emissions by 2-4%. Moving towards a more circular economy could bring benefits such as reducing environmental pressure, improving the security of raw materials supply, increasing competitiveness, boosting innovation, boosting growth, creating jobs (580,000 jobs only in the EU).



Consumers will also benefit from more sustainable and innovative products that will improve the quality of life and help them save money in the long run, [3].

In their 1974 'Hannah Reekman' research report entitled 'The Potential for Substitution of Manpower for Energy', Walter Stahel and Genevieve Reday outlined the vision of an economic loop (or circular economy) and its effect on job creation, economic competitiveness, resource saving, and waste prevention. The report was published in 1982 in the book entitled 'Jobs for Tomorrow: The Potential for Substitution of Manpower for Energy'. Considered one of the first credible support and sustainability centers, Stahel's main goals are to extend the life of products, create life-long assets, rebuild, and prevent waste. It also emphasizes the importance of selling services instead of goods - referred to as the 'functional services economy' and sometimes included in the wider concept of 'performance economy' that also promotes economic activity at the local level', [4].

Generally speaking, the circular approach is an inspired living system architecture that believes that systems created by us should work like organisms, processing nutrients that can later be used in the biological or technical cycle, hence the terms 'closed loop' or 'regenerative times' often associated with it.

The generic title 'Circular Economy' can be given and claimed by several schools of thought, all of which revolve around the same basic principles that they have refined in different ways. The idea itself, which is based on the analysis of living systems, is not new and can not be accurately dated or attributed to a certain author, but its practical applications to modern economic systems and industrial processes have gained momentum since the late 1970s giving rise to four prominent movements described below.

The idea of material flow in a circular fashion as an economic model was presented by Kenneth E. Boulding in his work *The Economics of the Coming Spaceship Earth*. The promotion of the circular economy was designated at the national strategy level in China at the 11th Five-Year Plan that began in 2006. The Ellen MacArthur Foundation, an independent charity founded in 2010, has more recently highlighted the economic opportunity of the circular economy. As part of its educational mission, the foundation has endeavored to unite the various complementary schools of thought and create a unified framework, thus widening the interest in concept, [2].

The circular economy can be considered a means of economic development with high efficiency and low emissions. Some scholars have contrasted the circular economy with the consumption and high emissions of the linear economy, which is normally associated with the industrialization process. The circular economy reflects the sustainable development strategy, through which natural resources are used with care and sustainability to protect the environment while the economy is developing in order to gradually achieve high efficiency, low-cost economy where pollutant emissions are reduced, and the recycling rate is high.

The circular economy can be considered as a kind of ecological economy that requires ecological rules to be imposed instead of market rules used to guide the economic activity of human society. Compared to the traditional economy, which is a form of linear economy, a path with a single sense of resource flow, characterized by high production and inefficient use of resources and strong emissions, the circular economy advocates a pattern of economic development that is much more in balance with the environment, characterized by low production, efficient use of resources and low polluting emissions.

All raw materials and energy in a circular economy are used and reused at the highest possible level so as to maximize the influence of economic activities on the natural environment.

The circular economy is, in essence, a market economy, with more resources allocated by the government than the market economy of the industrial age. The government, therefore, has an important role to play in the efficient functioning of the circular economy. In order to promote a circular economy, the EU has created a common and coherent framework: the 'Zero Waste for Europe' program. As an integral part of this common framework, the Commission endorsed the legislative proposal revising certain waste targets, objectives that have the goal of reducing the demand for scarce and expensive resources and increasing Europe's competitiveness.

The overall objective of sustainable ecological development is to find an optimal interaction between four systems: economic, human, environmental and technological. The optimal level of interaction corresponds to long-term development. For the model to be operational, it must support or apply to all subsystems that shape the dimensions of sustainable development, namely energy, agriculture, industry, investment, human settlements and biodiversity.

The circular economy requires the use of natural resources, energy and new technologies and the creation of more environmentally friendly systems in order to foster growth and create new jobs. This concept must create new models of sustainable consumption and production that do not force the Eco-system, figure 1. Sustainable development must be characterized by a dynamic and steady change, flexible adaptation and high-level research activities, all of which are closely linked to the conservation of the environment and the proper use of natural resources, [3].



Figure 1. The system of circular economy, [3].

Epoxy is a term used to denote both the basic components and the cured end products of epoxy resins, as well as a colloquial name for the epoxide functional group. Epoxy resins, also known as poly-epoxides are a class of reactive pre-polymers and polymers which contain epoxide groups. Epoxy resins may be reacted (cross-linked) either with themselves through catalytic homopolymerization, or with a wide range of co-reactants including polyfunctional amines, acids (and acid anhydrides), phenols, and alcohols. These co-reactants are often referred to as hardeners or curatives, and the cross-linking reaction is commonly referred to as curing. The reaction of poly-epoxides with themselves or with polyfunctional hardeners forms a thermosetting polymer, often with high mechanical properties, temperature and chemical resistance. Epoxy has a wide range of applications, including metal coatings, use in electronics / electrical components, high tension electrical insulators, fiber-reinforced plastic materials and structural adhesives, [4].

Epoxy resins are some of the best-performing resins currently available on the industrial market. Mechanical properties and resistance to thermal stress, as well as resistance to degradation over time, recommend them for use in most industrial environments against corrosion. Epoxy resins cover a wide range of applications and can be used as wall, carbon fiber, glass fiber, metal, plastics etc. By getting additional filler materials (glass, porcelain), the epoxy resin acquires superior mechanical and thermal

properties. The areas in which epoxy resins are used are many: metal coating, electronics and electro-technics, paints and adhesives, plastics with special properties in construction, [5] .

Epoxy resins are generally recognized as workhorse products among the category of thermosetting polymers due to their outstanding mechanical properties and good handling characteristic. The use of epoxy resins in industry extends back over fifty years since their introduction commercially and they find an extremely wide range of applications as coatings, adhesives and matrix resins in different fields like electronics, defense, aerospace industry etc. The main advantages of epoxy resins are their good mechanical properties, minimum shrinkage after cure and suitable weather, chemical and electrical resistance, [6].

2. Epoxy resins- types and modes of uses

In compression or transfer molding mixtures of epoxy thermosetting materials, with the exception of synthetic fibers used for mechanical properties, most fillers are inorganic:

- Flour silica has been used to increase viscosity and specific weight;
- Calcium carbonate (talc), ensures good machinability, some electrical properties and reduces the cost price;
- Fiberglass provides mechanical properties and shock resistance;
- Asbestos fibers improve erosion and shock resistance;
- Other fillers used are powders of iron, lead, aluminum, silver, wool, with specific uses, [7].

Epoxy resins are the most commonly used thermo set plastic in polymer matrix composites. Epoxy resins are a family of thermo set plastic materials which do not give off reaction products when they cure and so have low cure shrinkage. They also have good adhesion to other materials, good chemical and environmental resistance, good chemical properties and good insulating properties. The epoxy resins are generally manufactured by reacting epichlorohydrin with bisphenol. Different resins are formed by varying proportions of the two: as the proportion of epichlorohydrin is reduced the molecular weight of the resin is increased, [4].

Epoxy resins are some of the best performing resins currently available on the industrial market. Mechanical properties and resistance to thermal stress, as well as resistance to degradation over time, recommend their use in most industrial environments against corrosion. Epoxy resins cover a wide range of applications and can be used as wall, carbon fiber, glass fiber, metal, table mesh, and so on materials. The areas in which epoxides are used are many: coating of metals, electronics and electro-technics, paint and adhesives manufacture, production of plastic materials with special properties in construction.

Epoxy paints are used indoors because they are UV-sensitive (they are chalk-like) on the outside. However, they are very good as a primer which is resistant to corrosion and very good protection against water and humidity. That is why they are used as a first layer in the automotive or shipbuilding industry.

Epoxy adhesives are very resistant and are used in many areas: airplane, car, bicycle construction. You can stick wood, metal, glass, stone and some plastic. That's why when you are in the frame for a fabric, you have to keep in mind that there are few materials that do not stick very well, [5].

Epoxy resins are also used in the manufacture of printed circuit boards as well as for the installation of electronic assemblies because they provide very good electrical properties for good adhesion; produces an excellent resistance to the action of environmental factors; can be applied by the most different methods (pressing, casting, injection, screen printing, etc.). There are also different types of epoxy resins of which the most important are: bisphenolic epoxy resins are those based on condensation of bisphenol, Novolac epoxy resins (epoxy novolacs) are based on the phenol-formaldehyde polycondensation reaction, epoxy resins reinforced with aromatic amines, cycloaliphatic epoxy resins that are more flexible and have a higher resistance to ultraviolet radiation than bisphenolic or Novolac based resins.

Flexible epoxy resins are used when it is required that the encapsulation of the electronic assembly has a very good resistance to thermal and mechanical shocks (mechanical vibration). In doing so, it

works by reducing internal tension in classical epoxy resins (bisphenolic or Novolac based) by adding flexibility to the working network. Flexible polyamides, polysulphides, polycarboxylic acids and polyurethane are used, [8].

Chemical degradation of polymer wastes has attracted considerable attention because of its positive environmental impact, the enforcement of legislation with a strict control on landfill and incineration disposal, and a potential recovery of useful compounds. The extensive use of epoxy resin in metal coatings, paints, printed circuit boards, glass fiber or carbon fiber reinforced plastic materials, and structural adhesives has produced an environmental and economic awareness for the need to recycle these materials in a suitable process. Chemical depolymerization of epoxy resin is challenged by its cross-linked network structure, infusibility and insolubility in any solvents, [9].

Epoxy resin is usually formed by the cross-linking reaction of various polyepoxides with hardeners such as acid anhydrides and polyfunctional amines. Several degradation processes have been reported in order to decompose epoxy resin into low molecular weight compounds. Nitric acid solution was applied successfully for the decomposition of bisphenol F type epoxy resin, but it required an additional neutralization operation before the extraction of organic degradation products from the corrosive solution. On the other hand, effective chemical degradation of bisphenol A type epoxy resin hardened with amines in glycol or 1,4-butanediol at boiling temperature for 14 h suggested that the solvolytic cleavage of ether linkages was actually a transesterification reaction. Highly efficient recycling of anhydride-cured epoxy resin using a poly (ethylene glycol)/ NaOH catalytic system at 180 °C in 50 min under atmospheric pressure indicated a combination of ester hydrolysis and transesterification mechanism. In addition, recent chemical recycling of epoxy resin reinforced composites has exhibited excellent results by solvent-reagents such as methanol, ethanol, 1-propanol and acetone under supercritical or near critical conditions. Complete elimination of epoxy resin from carbon fiber surface was achieved providing phenolic compounds as the main products at 300 -325 °C and 9 MPa with a reaction time of 30- 50 min in subcritical water. The afore-mentioned processes either required a complicated product separation arising from the high-viscosity of polyols or were difficult to arrive at the conditions such as near critical water. Therefore, novel recycling technologies for epoxy resin should be developed to recover useful degradation products in a sustainable approach that is intrinsically innocuous to live things and the environment, [9].

Hydrogenolysis of aromatic ether linkages provided a new attractive alternative road for chemical degradation of macromolecular materials including the industrial product of epoxy resin and the lignin biopolymer. Hydrogen donors such as tetralin, decalin, 9,10-dihydroanthracene and cyclohexanol were successfully applied to degrade various thermosets including anhydride-cured epoxy resin, phenolic resins, melamine resins and unsaturated polyester. In addition, hydrogenolysis of phenolic ether linkages led to lignin depolymerization in supercritical methanol after hydrogen was produced from the catalytic methanol reforming. Supercritical alcohol was preferred over supercritical water not only since the critical conditions were less severe but also since hydrogen was *in situ* generated from the alcohol solvent. After complete decomposition of epoxy resin in supercritical isopropanol, Jiang *et al.* drew a conclusion that thermolysis played a key role in cleaving the chemical bonds of the epoxy resin, [9].

3. SWOT analysis for epoxy resins

SWOT analysis is a great way to assess the overall state of an organization so that a development plan can be developed to take account of its strengths, eliminate weaknesses, exploit effectively the opportunities and allowing for countering possible threats, [10].

Strengths and weakness are frequently internally-related, while opportunities and threats commonly focus on the external environment. The name is an acronym for the four parameters the technique examines, table 1:

Strengths: characteristics of the business or project that give it an advantage over others.

Weaknesses: characteristics of the business that place the business or project at a disadvantage relative to others.

Opportunities: elements in the environment that the business or project could exploit to its advantage.

Threats: elements in the environment that could cause trouble for the business or project.

Table 1. SWOT analysis for epoxy resins.

STRENGTHS:	WEAKNESSES:
Epoxy resin is water resistant and chemical agents. - Aliphatic resin reagents offer product flexibility - The molecular weight of an epoxy resin can be controlled by the acid / alcohol ratio. - Epoxy waste is treated and eco-eliminated. - epoxy resin waste management is integrated into socio-economic life; - Products based on epoxy resins are resistant over time, protected installations have a longer life. - Epoxy resin exhibits a low permeability. - Epoxy resin exhibits wear resistance, mold resistance, can also be used in the food and pharmaceutical industry. - Epoxy resin can be applied easily and quickly, is a renewable and biodegradable resource.	The soil epoxy is poorly soluble in oil, alcohol and partially dissolved in gasoline. - Epoxy paints are used indoors because they are sensitive to UV radiation (outside are chalk) on the outside. - Epoxy resin is toxic to burning. -Epoxy resin can cause eczema contact allergies to handle epoxy powders in the case of sensitized persons. - Epoxy resin can cause respiratory problems and allergies. -Epoxy resin shows low adhesion if the cracks on which it is applied are not cleaned.
OPPORTUNITIES	THREATS
- Intensive industry development will lead to the use of more resin epoxies. - Developing the circular economy will lead to new jobs. - The use of epoxy resins in industry is an important step in the recycling and prevention of waste formation.	- Developing difficulties in collecting and transporting waste collected from epoxy resin waste may pose a threat to the development of the economy of the circular economy. - High costs for recycling waste can be an impediment to circular economy development. - Modernization of industrial processes with regard to waste recycling can be difficult.

4. Conclusions

The concept of circular economy is broader, adding a new segment to the life cycle of products, namely recovering materials from dismantling, recycling, and reusing them as secondary raw materials in other early-life products. European Commission experts believe that the implementation of the circular economy could help the EU economy become more competitive and remove the pressures on resources and the environment.

A first strategic step was made in 2014 through the European Commission's Communication "Towards a Circular Economy: a" zero waste "program for Europe, followed in December 2015 by the adoption of the Circular Economy Package (Package), which includes the Action Plan, List of initiatives accompanying the plan and 4 legislative proposals on waste.

Epoxy resins are some of the best performing resins currently available on the industrial market. Mechanical properties and resistance to thermal stress, as well as resistance to degradation over time, recommend their use in most industrial environments against corrosion.

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