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E-mail: jzus@zju.edu.cn

Book review:

Would recycled plastics be a driving force in concrete technology?

Lech CZARNECKI
The Instytut Techniki Budowlanej (ITB), Warsaw 00-611, Poland
E-mail: l.czarnecki@itb.pl
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1 Introduction

The aim of this paper is an attempt to answer the title question. In less than a century concrete has become the most widely used construction material and in less than half a century it has become difficult to imagine concrete without polymers. However, what about the future?

I have already tried to answer a similar question (Czarnecki, 2015; Czarnecki et al., 2018). However, the positive responses, as a rule, are limited to niche concretes with special properties, such as "repair polymer concrete" (Czarnecki, 2018) or "future concrete", "printable concrete", but never commonly-used ordinary concrete. This time it may be different. The inspiration for this paper is a book (Pacheco-Torgal et al., 2019) entitled "Use of Recycled Plastics in Eco-efficient Concrete" edited by world-renowned F. PACHECO-TORGAL (University of Minho, Portugal) and his notable colleagues: J.M. KHATIB (Beirut Arab University, Lebanon and University of Wolverhampton, UK), F. COLANGELO (University Parthenope of Naples, Italy), and R. TULADHAR (James Cook University, Australia).

The book, which has 20 chapters is written by 48 authors from 13 countries, and is global in subject coverage as well as in authorship. It presents a holistic approach, and reframes the total problem. The driving force will not be virgin polymers, but plastics, and not newly formed ones, but recycled waste.

This move, from virgin polymers into recycled waste plastics and addressing the result as eco-efficient concrete opens a new technological era. Requirements are changing; now we are looking not only for "better concrete" but also for concrete with an acceptable performance from worse or even waste components, in short: "better from waste". It is a necessary development in the search for sustainable development. A book which stresses in its title "eco-efficient concrete" encourages great expectations. However, it should be emphasized that almost every chapter of the book ends with the phrase "further studies are needed".

2 A piece of history

When synthetic polymers were added to concrete there was much interest in the idea of an amalgam between the polymer, as a product of advanced technology, and concrete, a very traditional construction material. But the polymer at that time costed ten times more than Portland cement, the most expensive component of concrete. However, with time, polymers in concrete have overcome a lot of problems and passed several technological milestones (Table 1) and have become construction materials tailored for various applications.

Until now, the polymer has mainly acted in the continuous phase of the concrete. It acts as a binder modifier if its proportion is below 5% of the cement mass. Above that value the polymer is able to create a continuous network and acts as co-binder together with Portland cement.

ORCID: Lech CZARNECKI, https://orcid.org/0000-0003-3340-9075

The book actually gives more than its title promises. Concrete is commonly associated with Portland cement concrete. However, almost 100 pages (Chs. 12–15 and 20) are relevant to asphalt concrete mixtures.

3 Essence of recycled waste plastics in eco-concrete

The aim is always "better concrete". However, it is now obvious that "better concrete" means "sustainable concrete". The need for sustainable development should be paramount. "Eco-efficient" is not a question of improving the technical performance of concrete but rather it is concerned with converting waste products into new useful products and objects. This process can save resources and lower greenhouse gas emission. At present, plastics waste can be treated by three methods (Geyer et al., 2017) each approximately an equal share of the total: landfill, incineration, and recycling. Incineration is euphemistically called "energy recovery", but is similar to landfill as an environmental threat.

This book is focused on the use of recycled plastics in concrete with the assumption that it will be the trend of future developments. After recycling, there are three main products differentiated by the kind of plastics: granulates, fibers, and dioctyl terephthalate —used as a modifier of Portland cement binder (2%–4% by mass of cement). All of these are well set out in the book (Fig. 1).

The use of polymer fibers in Portland cement concrete (Chs. 16–19, from (Pacheco-Torgal et al., 2019), the same book unless otherwise stated) and in asphalt concrete (Ch. 20) as a very effective modifier is already well established. Replacing the virgin polymer fibers with recycled waste plastics fibers seems to be a standard development. The same applies to expanded polystyrene (Ch. 7) or polyolefin concrete (Ch. 8). Styrofoam is already a well-known addition to concrete, and replacing these original polymers with recycled plastics will be expected and should be welcomed.

The use of granulated recycled plastics in asphalt mixtures (Chs. 12–15) also promises improvement in technical performance. The situation is diametrically different in the case of partial substitution or addition to the aggregate (fine aggregate) in Portland cement concrete (Chs. 6–10). This is not so obvious because recycled plastic granulates are plastic in comparison with the mineral (quartz) aggregate grains and, among other issues, the adhesion between these recycled granulates and the Portland cement binder is very

Table 1 Concrete–polymer composites (C–PC) milestones according to international congresses on polymers in concrete (Czarnecki et al., 2018)

No.	Year, City	Motivation	Remark
1	1975, London	Use of polymers in concrete as a new technology	Precast elements and bridge deck overlays
2	1978, Austin	C–PC versatility proved, and applications widespread	Focused on the use of polymers in concrete
3	1981, Koriyama	C–PC is used in a different area (repair and overlays)	Shrinkage, creep, and durability of C–PC
4	1984, Darmstadt	"Material model" appears as a category	Epoxy cement concrete and glass reinforced polymers concrete (GRPC) panels
5	1987, Brighton	Tailoring C–PC properties for various applications	Materials models for performance control
6	1990, Shanghai	Worldwide use of polymers in concrete comes true	Interaction between polymers and concrete
7	1992, Moscow	How good C–PC is good enough?	Evaluation, simulation and optimization
8	1995, Oostende	Mathematical modelling and design for durability	High strength PC and polymer fiber concrete
9	1998, Bologna	Micro-macrostructure relations for new C–PC	Nanotechnology and recycled plastics in PC
10	2001, Hawaii	How polymers develop sustainable C–PC	Self-repair PCC; metallic monomer PC
11	2004, Berlin	Integrated model polymer cement concrete (PCC), hardener-free epoxy	Water soluble polymer in PCC
12	2007, Chuncheon	Sustainable C–PCs and nanotechnology in C–PC	Extensive studies of C–PC performance
13	2010, Madeira	High performance C–PC (HPC–PC)	Interfacial zone of polymer in concrete
14	2013, Shanghai	Modelling of cement and polymer hardening	Polymer film forming thermodynamics
15	2015, Singapore	C–PC potential aging	Self-sensing PC and nano-modified PC
16	2018, Washington	Are polymers still driving forces in concrete technology?	

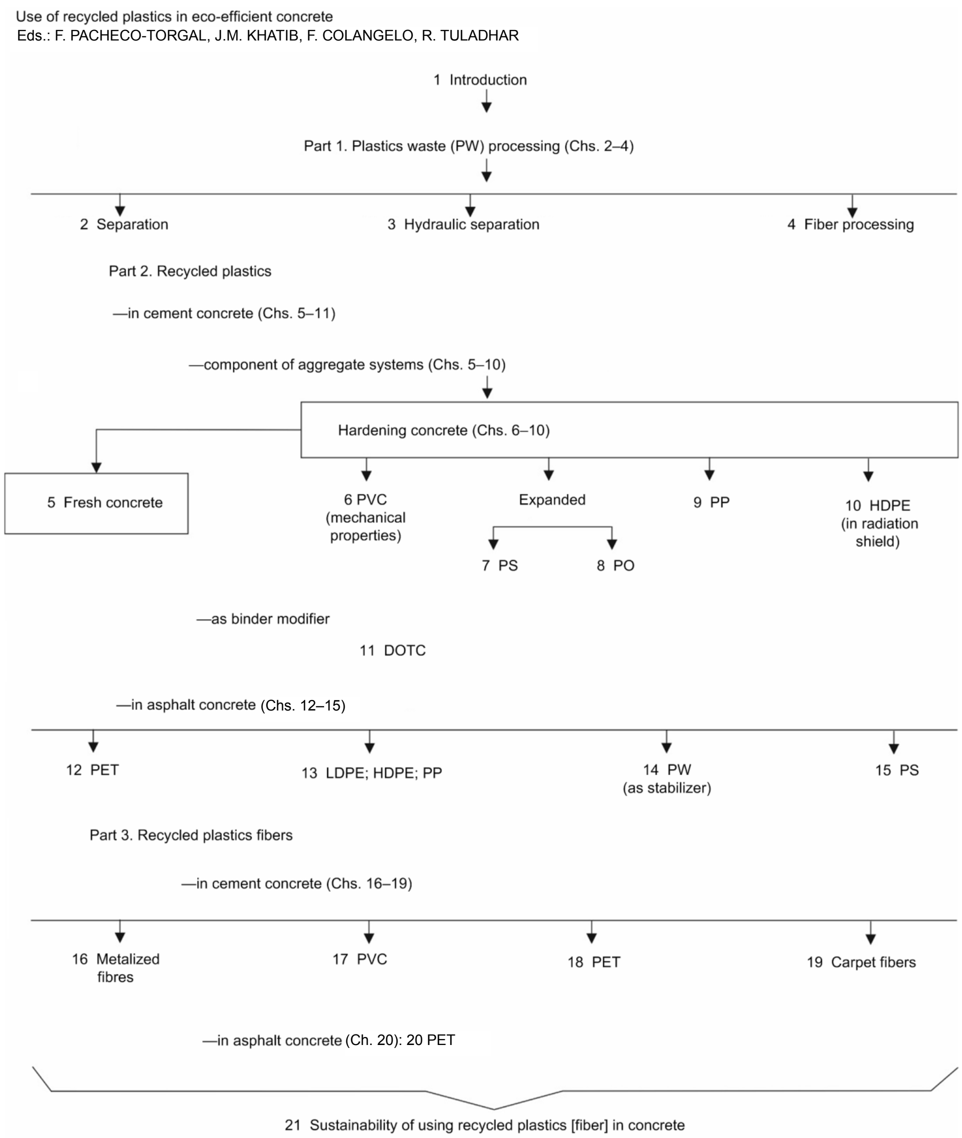

Fig. 1 Structure of the book "Use of Recycled Plastics in Eco-efficient Concrete"
PVC: polyvinyl chloride; PP: polypropylene; HDPE: high density polyethylene; LDPE: low density polyethylene; PS: polystyrene; PO: polyolefins; DOTC: dioctyl terephthalate concrete; PET: polyethylene terephthalate

problematic. However, the decisive circumstance is that Portland cement concrete production is 1000 times higher than that of asphalt concrete. This dictates the potential of plastic waste management. The question arises not because concrete needs more polymer, but that the environment should not accept any more deposited plastics—any more plastics garbage. Until now the polymer in a concrete–polymer composite plays the role of a co-binder or binder modifier. Recycled waste plastics will be basically and almost solely (compare Ch. 11) used as "plastics aggregate innovation". It means a change of the technological paradigm: from "original polymer as a co-binder" to "recycled waste plastics as aggregate additives". Creating awareness of the necessity to build and prove a new technological paradigm is the fundamental merit of the book.

For whom was the book (Pacheco-Torgal et al., 2019) written? It contains a mixture of fundamental thoughts and practical advice. The readership should be wide and various, such as researchers, students, engineers, technologists, formulators, designers, producers, developers, and many many others. In 2016, a critical review of "Use of recycled plastics in concrete" (Gu and Ozbakkaloglu, 2016), summarized the then current published literature as 84 papers. In this work (Pacheco-Torgal et al., 2019), after less than two years, more than 10 times more references are cited (987). It documents how the topic is hot and also shows the value of a book of almost 1000 papers encapsulated in one comprehensive volume.

The book can be read in many different ways. Read from cover to cover, it gives an overview of the important problems and of the diversity of inspirations. Read more selectively, individual issues can be explored. You can store the book on a shelf and treat it as an encyclopedia that contains fresh details and fills a gap in your knowledge. In both cases, an extensive, clear index will greatly help. However, two important matters have been omitted. These are compatibility and synergy. The compatibility between recycled plastics and Portland cement, as well as other components, is an overriding requirement and should be properly accented. The understanding of synergy can be important in consideration of performance deficits, sometimes created when replacing virgin polymer with recycled waste plastics. There is also an absence of a list of symbols and abbreviations such as AASHTO, AC, BDIC, BF, BOF, DSC, FHWA, MPW, HMA, ITS, KSA, OBC, PE, PET, DOTC, PO, PP, RSI, SBS, SRM, EAF, VFA, VMA, WHVOC, TRB, and many more. For the layman or even for the student it will be difficult to go through a sentence like (p.312 in this book): "The most commonly used PMA type in SMA is with an elastomeric polymer SBS (…) reported that SMA incorporating SBS PMA produced mixes…". However, after flipping through a few pages of the book, you will get used to it.

4 Empirical view: determinants

A few numbers roughly estimated: (1) plastic production is 300 million tons annually; (2) cumulative plastics production is 8 billion tons; (3) seven billion tons of plastics is in landfill.

Many plastic products have a very low product lifetime, so they typically become waste within six months.

These numbers defined the meaning area by contrast with the validity area which has been considered in the previous section. Plastics are one of the most durable materials. They may linger as long as 450–600 years without fully decomposing, while polluting bodies of water, harming aquatic life, and damaging environmental esthetics (Ch. 3). Durability, one of the fundamental advantages of plastics, paradoxically turns into the main obstacle to waste management. Most plastics formed by hot processes can be recycled no more than twice. It means that recycling only delays rather than avoids final disposal (Geyer et al., 2017). Frequently this delay may be estimated at no more than two years. The numbers illustrate how big the problem is. In this book (Pacheco-Torgal et al., 2019), it is shown how to remove waste plastics from landfill and store them in concrete. The lifetime of concrete construction is more than 50 years. If we then can provide for recycling of the concrete, it could be several times more. However, in this book (Pacheco-Torgal et al., 2019) recycling of concrete containing recycled waste plastics is not yet considered (first edition).

Annual Portland cement concrete production is around 5 billion tons. The information on page 4 (Pacheco-Torgal et al., 2019) "25 gigatons" seems to be an overestimate; the amount per head of the world's population is in the range 0.5–1.0 ton of concrete per capita, and not as much as 3.5 tons per capita. This concrete contains around 4 billion tons of aggregate. If we assume that it will be possible to replace 5% of concrete by volume (Thorneycroft et al., 2018) or around 8% of aggregate by mass (Chs. 5–10) with plastics, it will mean that annually 300 million tons of recycled waste plastics would be consumed in concrete. Consequently—according to the current state of the art—optimistically there would be no further increase in plastics in landfill. Moreover, bitumen asphalt production is approximately 100 million tons (Factfish.com, 2019). Taking into consideration an optimistic approach that 10% of plastic replacement will be possible (Chs. 12–15 and 20) the waste plastic in landfill will decline, but very slowly. It is obvious that it is not a question of whether recycled plastics will be used in concrete (compare the title of this book), but rather of the rate of their consumption and when the process will start.

5 Is the work a technological breakthrough?

At this early stage, it is difficult to assess (Winnink et al., 2018) whether it is a breakthrough. But by intuition it is, and should be, a breakthrough because of its real novelty, which can have a huge impact on further technological development related to the most commonly used material—the concrete from which our cities are built. Right now, it is an important signal of great change in concrete technology, and the book plays a pivotal function. There are several fields where a new breakthrough can be expected to occur. Undoubtedly, concrete technology is one of them. However, such breakthroughs always seem to be difficult to discover (Betz, 2018).

The book links together the concrete—the absolutely premier construction material in which the works of our civilization are created—with plastics wastes, which are a burden on civilization and has accented recycling as a way of civilization survival. Using the word "civilization" three times in a discussion of the book indicates the magnitude of the importance of the issues covered by it. It is a rich treasure-house of the new thoughts, principles, experimental results and interpretations that have led to the development of new methods in concrete technology and it is essential reading for envisioning their future.

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