Review
Received January 12, 2006
Accepted for Publication March 26, 2007

Concrete-polymer Composites : Trends Shaping the Future

Lech CZARNECKI

Warsaw University of Technology, Department of Building Materials Engineering
00-637 Warsaw, Armii Ludowej 16, Polska-Poland
E-mail : L.Czarnecki@il.pw.edu.pl

The paper presents the state of knowledge and technology on the concrete-polymer composites (C-PC) and the prospects of their development. We can formulate a general thesis : the future of C-PC lies not only in technology, but also in ability to manage it. New arrangement of the research facts — new understanding of the nature of the material and the thrust for further development in application and theory are the present expectations. There are many old questions about material selection, its usability, compatibility and durability. The new questions are about material model.

It is difficult to expect completely new material concept in C-PC domain in the nearest future. It would be rather better using of polymers — more economical and in more synergetic way. It also means more sophisticated formulation and way of preparation. There are various findings in other disciplines, which would affect the development of the concrete-polymer composites. Some of them as well as a creation of such ideas are discussed in the paper.

Key Words : concrete, polymers, designing, application, trends

1. INTRODUCTION

The main idea of the ICMR 2005 AKITA is beneficial integration of various separate ideas in materials science and engineering, the modern and traditional ones, into new concept which could provide a promising view into 21st century. Concrete-Polymer Composites (C-PCs) by themselves are the good exemplification of the concept. C-PCs are the results of implementation the modern polymers into traditional concrete technology. Using of polymer concretes in construction activity is not quite new idea. Building materials have been modified be natural polymers even in III—II millennium B.C. [1].

Concrete is the most commonly used and the oldest man-made material. In this meaning it could be treated as the civilisation necessity. For 50 years concrete is modified in various way with polymers on the engineering background. This creates a new opportunity and still new problems to resolve.

Nowadays, the age of concrete, in the singular, has passed, we have definitely entered, the era of concretes [2] ; C-PCs are one (or rather three — compare chapter 2) of them. Contemporary era of C-PC has started in 1923, when Cresson patented polymer-cementitious materials (British Patent 191474). During the first International Congress on Polymers in Concrete in London, 1974 the "pioneering time" created the "pioneering spirit" : "add polymer into concrete-it could be only better". However, further experiences will show that not always. The "trials and tribulations" time has started. Beside of that, material cost of polymers is 10 to 100 times (depending on the type) higher than that of portland cement according to mass unit and 5 to 25 times higher according to volume unit. With time the important questions arise [3] :

- how to evaluate the efficiency of polymer application?,
- how to create synergy of interaction between polymer and other ingredients of concrete?

The problem of the "mechanism"-how polymer improve concrete (P.Seidler, 2001), the influence on shrinkage internal stresses (Kawakami, 1981), durability, reliability and much more [4]. Finally, Y. Ohama addressed all the questions under t he "roof" called the "sustainable concrete-polymer composites" [5]. In general, it means "from better understanding of the material nature to more rational application" (eco-application).

There is no competition for using C-PC in sutuations mentioned below :

- Polymer-Cement Concretes (PCC) as the rapid-repair means, particularly when we should fix up the structures after explosion, earth-quake, etc.,
- Polymer Impregnated Concretes (PIC) as the way to preserve monuments and old buildings,
- Polymer Concretes (PC) always when we need to assure durability under heavy chemical attack, e.g. vinylester resin concrete electrolytic tanks in copper industry.

2. FOR WHAT POLYMERS IN CONCRETE?

Polymers add to concrete. For what? For "better concrete", always. The general concept of polymer concrete composites — from technical point of view — involves a process by which chemicals (monomers, oligomers, prepolymers, polymers) introduced into a concrete mix and in the case of chemical activity are subjected to polymerisation and polycondensation by thermal-catalytic or other systems (Figure 1).

An infinite number of different mixtures depending on the chemical nature of components, their contents and manufacturing process can be found in this way [4].

Concrete-polymer composites (C-PC) are concrete-like polymer composites, that may contain portland cement.

Polymer modified concrete (PMC) is concrete produced using a low dosage of polymer ($\leq 5\%$ by weight) incorporated into portland cement concrete to affect mainly, if not only, the rheological properties of the mixture. This type of composite is also called Latex Modified Concrete (LMC).

Polymer cement concrete (PCC) is a composite wherein either a non-reactive polymer (latex) or a reactive monomer (resin) (resin) is added to a fresh portland cement concrete mixture. More precisely, PCCs can be described as follows :

- premix PCC, in which the modifying additive is added to the fresh concrete in the form of complete polymer (latexes, elastomers, or thermoplastics). That is, the polymerization of the modifying additive has taken place before addition to the concrete,
- postmix PCC, in which polymerization components (chemically reactive synthetic resins or prepolymers and monomers) are mixed with fresh concrete, and the polymerization is obtained by chemical means, inside the concrete, along with hydration of the cement.

Polymer impregnated concrete (PIC) is a composite formed by infusion of polymers into the pores in portland cement concrete (after it has hardened).

Polymer concrete (PC) is a composite formed using aggregate and a polymer binder (no portland cement is used).

In the recent ACI documents [6] PMC and PCC are treated altogether, and called polymer modified concrete.

From the definitions, the concrete polymer composites differ by way of how a polymer is introduced into a concrete, either with the mixing water (PCC), with the concrete mix (PCC and PC), or by some special means directly into the hardened concrete (PIC). Moreover, concrete-polymer composites differ in ratio of the substitution of polymer for portland cement – in the ultimate case, cementless concrete (PC). Polymers are introduced in various forms – monomer, liquid resin, dispersion or solution as well as redispersible powder.

The main task of using polymer in concrete is always "better concrete". Concrete polymer composites could bring vastly increased tensile strength and better adhesion to an existing Portland cement concrete as well as frequently improve other properties e.g. abrasion resistance, higher water and vapor tightness and resistance to frost and chemical attacks. Regarding to the PCC a Portland cement is still an essential material in making concrete, but .... it is no longer the most important due to the nature of the composite/components interaction (synergy!), it is difficult to decide which component is the most important. Perhaps polymer?! Surely, in the case of PC – polymer is the most important.

3. HOW THE C-PC MAKE PROGRESS?

It is very useful to take the lecture from the history of International Congresses and Symposiums on Polymers in Concrete (Figure 2a). The conference output could be presented in the form of life curve ("snake curve") of discipline. The analysis of ICPIC output (Figure 2b) gives the impression of very quick development in the 1970s and the 1980s, but near stagnation in the early 1990s. Some optimistic signs of change, evident in the positive turning point on the C-PC development curve, could be seen in the 1995 Congress in Oostende. The output of the Congresses in Bologna, Hawaii and Berlin confirmed the optimism. The "life curve" representative for Asia Symposia (since 1994) even more abruptly is going up. However, if we untangle the life curves ("snake charmer process") – the fundamental differences will be obvious (Figure. 2c). In Asia "the science get ahead application" contrary to worldwide situation, where "the science behind application". Certainly, this judgment is done a little subjective way, however it is of interest and worth to recognize. One of the significant changes in the development of C-PC is the shift in material type most often discussed at each of the congresses. Until 1995, PC was unquestionably the dominant material, with nearly half of the papers focused on PC. Recently, however, the picture has changed dramatically. In the last four congresses, over 50% of the papers have focused on PCC, about 40% have focused on PC, and

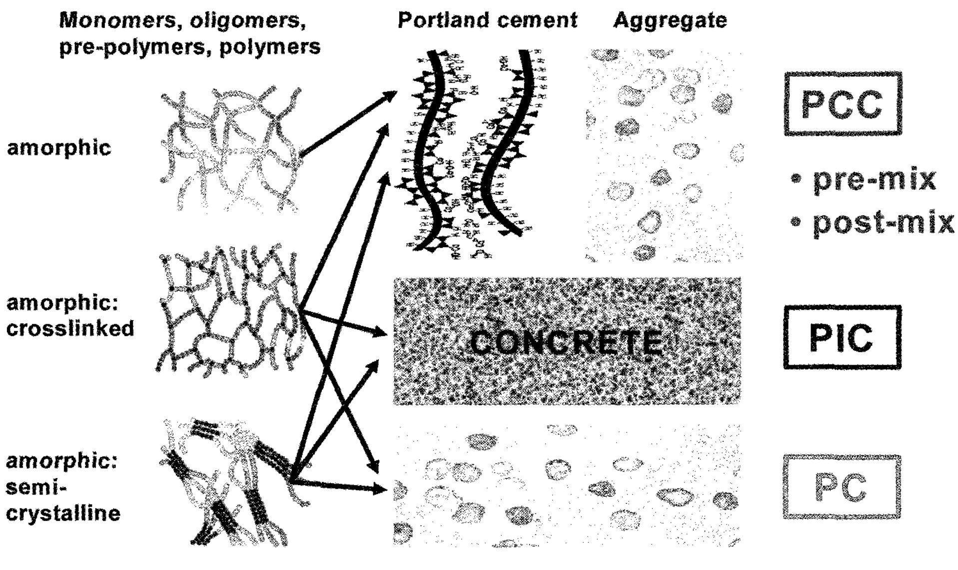

Figure 1 Schematic presentation of C-PC family [4]

less than 10% have focused on PIC [4]. Polymer impregnation concrete technology was occurred too complicated and over costed.

The top position PCC owes to the Integrated Model of Microstructure Formation (IMMF), which has been recently elaborated [8]. It gives the good evidence that C-PCs (PCC, at least) come of age and the "material model of microstructure formation" is used for rational application.

4. SEARCHING FOR SYNERGY ON THE MATERIAL MODEL BASE

Synergy is the simultaneous action of components, which together give greater total effect than the sum of their individual effects. The interactions between components of the concrete-polymer composite should be considered as the integral part of the material model and the basis for material designing and optimisation [9,10].

Presence of polymer in the concrete affected its properties in various ways (Figure 3) :

- properties of the polymer take part in forming the properties of the material as a whole, according to the additive mechanism,
- polymer causes modification of the concrete microstructure, leading to the changes in its properties (synergic effects),
- the polymer particles show the orientation – the polar groups are oriented towards the aggregate (synergic effects).

Moreover, polymer affected the portland cement hydration, slow-down of the process is observed. In some cases chemical reactions of polymers with components of the cement paste take place, sometimes unfavourable for the composite end-properties. Polymer influenced also on the transition zone between the portland cement paste and aggregate. The continuous film of the polymer can "bridge" the micro-cracks in the cement matrix and in the transition zone (Figure. 4).

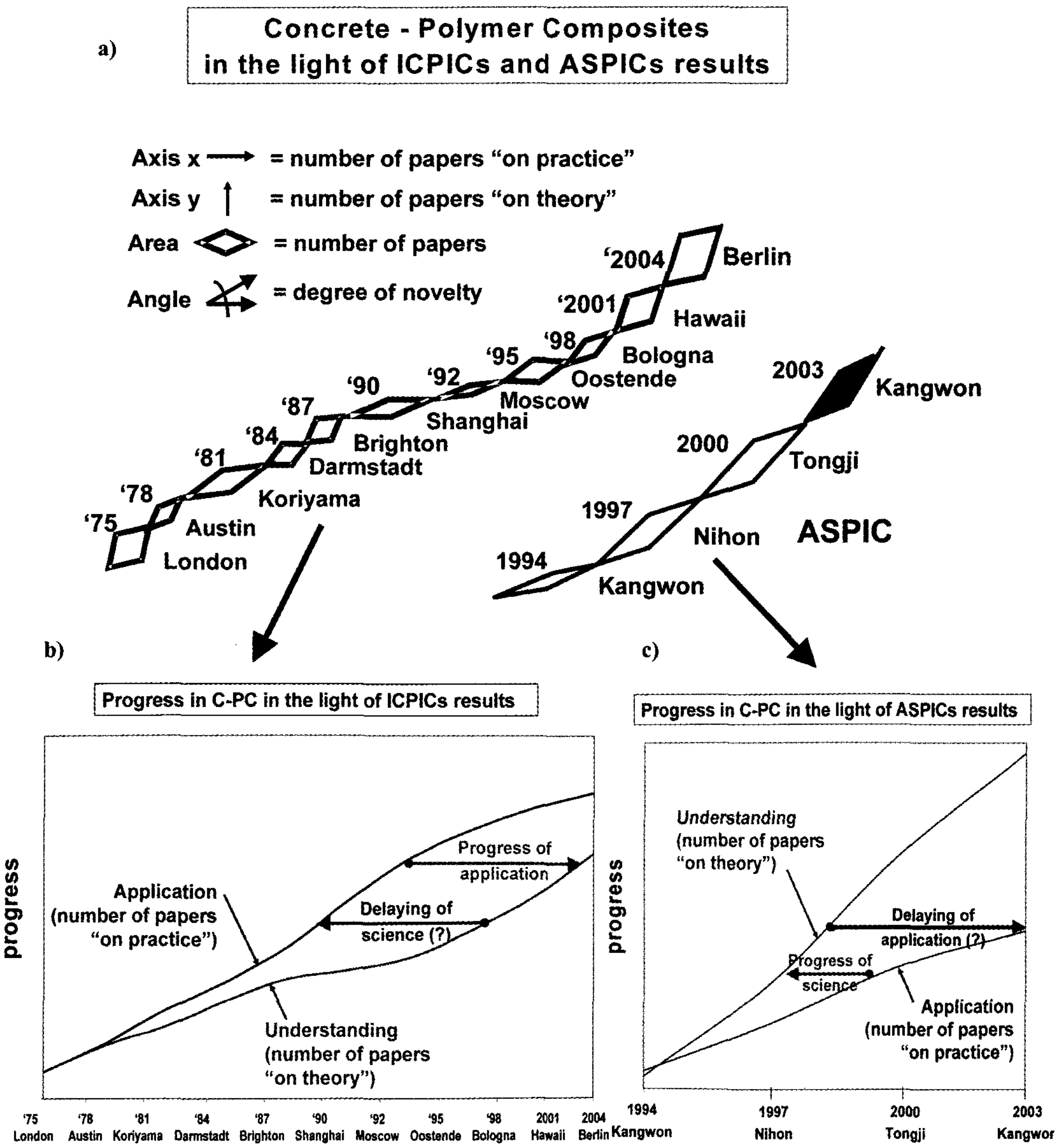

Figure 2 Progress of C-PC – "snake curves" (a) as indicated by ICPICs (b) and ASPIC (c) {4,7}

5. C-PC : NICHE CONCRETE OR COMMODITY CONCRETE? C-PC PECULIARITIES AND APPLICATIONS

Almost all produced concrete contents suitable admixture and lot of admixtures are polymers [12]. It is also worthy of note that some polymer－containing (plus silica fume) concrete compositions have changed names and shifted for high performance and high-strength concrete [4]. In late seventies [13] of the previous century C-PC kept all mechanical strength records : $f_c=70$, 100 and 150 MPa for PCC (Kesai Y, Matsui I, Fukushima Y－1981), PC (Kukacka L, and co－1978) and PIC (Fukuchi T, Ohama Y－1976), adequately. In the same time－80 MPa has been qualified as the upper limit practically available for portland cement concretes. Concrete with compressive strength higher than 100 MPa has been described as an "exotic concrete" [14]. Nowadays the European Standard for concrete EN 206-1 recognized the ordinary concrete with compressive strength until 60 MPa and high strength concrete with compressive strength 60-100 MPa. However, the high level [15] of tensile strength $f_t=20$ MPa and flexural strength $f_f=50$ MPa is still an outstanding advantage of PC (table 1).

The addition of polymers to an existing portland cement concrete mixture could provide increased tensile strength, better adhesion, better abrasion resistance, higher resistance to water and vapour transmission, or greater resistance to frost or chemical attacks.

Practical application of concrete-polymer composites is diversified. After the period of domination of polymer (resin) concrete, now the most common used material from that group is polymer-cement concrete. Its main advantage is the possibility of achieving of significant improve of the properties compared to the portland cement concrete without the need for big changes in technology. Manufacturing of resin concretes is more complicated. In the case of PIC, full impregnation is extremely complex and expensive process and this is why it is not used on site in practice, and only rarely in pre-fabrication.

Concrete-polymer composites are widely and successfully used in repairing and protection of reinforced concrete structures, as well as for overlays and industrial floors. Polymer mortars are used for making the industrial floors. Resin concretes (polyester and vinylester ones) are widely used in production of pre-cast elements, particularly intended for using in chemically aggressive environment－tanks, pipelines, sink basins, floor drains, tunnel linings, etc.

6. CONCLUSIONS

During the past 50 years [4] concrete-polymer composites have made tremendous progress. They continue to be very promising materials for new applications and for stimulating new research.

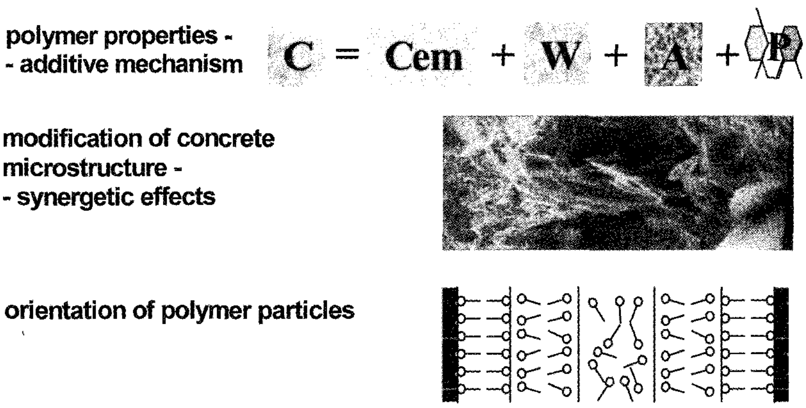

Figure 3 Influence of polymer on concrete properties

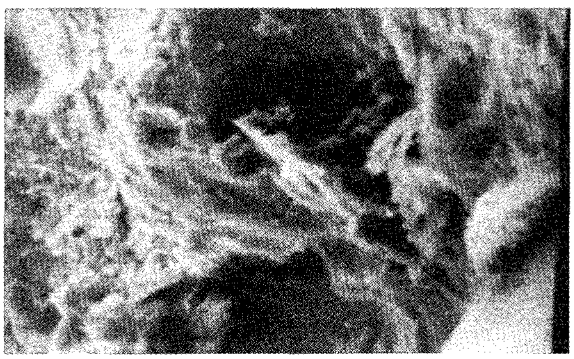

Figure 4 Bridging of microcracks by polymer in epoxy-cement composite, SEM 800X

Table 1 Properties of concrete-polymer composites compared to Portland cement concrete [10, 24]

Property	Cement concrete	Polymer-Cement Concrete, PCC	Polymer Impregnated Concrete, PIC	Polymer Concrete, PC
Compressive strength, MPa	10–60 (> 60*)	10–75	100–200	40–150
Flexural strength, MPa	1.5–7 (> 7*)	3–12	7–35	4–50
Tensile strength, MPa	0.6–3.0 (> 3*)	4–9	4–17	4–20
Modulus of elasticity, GPa	15–30	10–25	30–50	7–45
Poisson's coefficient	0.11–0.21	0.23–0.33	0.20–0.25	0.16–0.33
Coeff. of linear thermal expansion, $10^{-6}\cdot K^{-1}$	10–12	11–15	10–17	10–35
Water absorbability, %	4–10	1–3	0.5–1,5	0.5–3
Chemical resistance	poor/average	average /good	good /very good	very good / excellent
* For High Performance Concrete (HPC)				

Acknowledgments. This work has been prepared in the framework of Warsaw University of Technology grant — grant No. 504 G 1084 2815.

REFERENCES

[1] Chandra S., "Historical background of polymers used in concrete", Proc. of 8th Int. Congress on Polymers in Concrete, Oostende, pp.3-11, (1995)

[2] Malier Y : Foreword to High-performance concrete, PC Aitcin, E & FN Spoon, (1998)

[3] Czarnecki L., C-PC make a challenge, XI International Congress on Polymers in Concrete, Berlin, (2004)

[4] Czarnecki L., Polymers in Concrete, Concrete International, 8/2005, pp.1-7

[5] Ohama Y., Recent progress in research and development activities of concrete-polymers composites in Japan. Proceedings of X International Congress on Polymers in Concrete, Hawaii, (2001)

[6] ACI 548.3R-95, State — of — the Art. Report on Polymer Modified Concrete, Detroit, pp.45, (1995)

[7] Czarnecki L., Concrete-Polymers Composites : challenges and possibilities, Proc. of 4th Asia Symposium on Polymers in Concrete, Chuncheon, Korea, (2003)

[8] Beeldens A., Van Gemert D., Schorn H., Ohama Y., Czarnecki L., From microstructure to macrostructure : an integrated model of structure formation in polymer-modified concrete, Materials and Structures, 38/2005, p.601-607

[9] Czarnecki L., Łukowski P., Chmielewska B., Statistical analysis of the synergetic effects in epoxy conretes. Proc. of XI Int. Congress on Polymers in Concrete, Berlin, pp.201-208, (2004)

[10] Czarnecki L. and Lukowski P., "Optimization of polymer-cement concretes", In : "Optimization methods for material design of cement-based composites" (ed. A.M.Brandt), Modern Concrete Technology 7, E & FN Spon, London and New York, pp.231-250, (1998)

[11] Czarnecki L. and Lukowski P., "Influence of polymer admixtures and additives on durability of concrete", Cement Wapno Beton, No.1, pp.38-47, (2004)

[12] Ohama Y., "Recent progress in concrete-polymer composites in Japan", Proc. of 3rd Southern African Conference on Polymers in Concrete, Johannesburg, pp.207-227, (1997)

[13] Czarnecki L., The status of polymer concretes, Concrete International, 7/1985, pp.47-53

[14] Saucier, Kenneth L., High Strength Concrete : past, present, future, Concrete International, 6-1980, pp.46-50

[15] Kawakami M, Fokushige H, Suzuki S, Stress and strain due to setting shrinkage of FRPM, Proc. of 4th ASPIC, Chuncheon, pp.243-254, (2003)