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Ecomaterialization by Improvement of Materials Efficiency of Carbon and Glass Short-cut Fiber Reinforced Cement Composites (CFRC and GFRC)

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Methods of ecomaterialization of short-cut fiber reinforced cement composites (FRC) are shown, from the viewpoint of improvement of materials efficiency. We propose the fundamental schemes of ecomaterials design of FRC as the system of production, selection and evaluation of desired FRC corresponding to the required performances of structural, durability, fire-proofing and -resistance and ecobalance. As concrete ecomaterials technology, we tried to convert FRC into ecomaterials by experimental study by using recycled materials. Fundamental behaviors of fresh and hardened pitch type, general purpose class carbon short - cut fiber reinforced cement composites (CFRC) using ecocement (recycled cement from urban waste) and pulverized waste FRP powder as replacing materials for ordinary Portland cement, and using recycled fine aggregate as replacing materials for river sand are reported. We found that material properties of these CFRC were comparable to or rather improved compared with ordinary CFRC using only virgin resources. On the other hand, we also tried to carry out experimental study on ecomaterialization of glass short-cut reinforced cement composites (GFRC) by using ecocement and pulverized waste FRP powder, and obtained almost the same results. These are considered as effective ecomaterials technologies of improvement of materials efficiency for virgin resources.
Key words: Short-cut fiber reinforced cement composites, Ecomaterialization, Materials efficiency, Recycled materials, Fundamental behaviors

1. INTRODUCTION

The concept of composite materials is known empirically from old age. Adobe bricks used in the Central East since ancient Egypt and Mesopotamia are kind of short-cut fiber reinforced clay reinforced with natural plant fibers. Earthen walls used in Japan used from old times are kind of double-reinforced clay reinforced both with short-cut fiber of natural straws, and with lattices of bamboo which is considered as natural continuous fiber reinforced composite. Many building material are used as some composites and very rarely as homogeneous single- phase materials. From microscopic point of view, even natural wood as one of the most important structural materials in housing is considered to be uniaxial cellulose fiber reinforced composites with lignin as binder. Technology of composite materials, however, has drastically progressed recently through the development of materials science and the technological innovation with the development of advanced artificially fibers such as carbon, aramid, and glass.

Recently the concept of resources circulation and the environmental harmony (eco-balance performance) have been appreciated as important in building field as well as other industrial fields, in order to establish sustainable eco-society considering the balance among economy, the environment/landscape, and safety/long service life on and after the 21st century [1) 2)]. Effective and rational use of environment–conscious materials (ecomaterials) as building materials, or the conversion of building materials into ecomaterials (ecomaterialization) are loudly cried for in these contexts. Short-cut fiber reinforced cement composites (FRC) using new advanced fibers such as carbon, aramid and glass have very useful[3)] as lightweight, high strength and highly-durable component materials of, for example, new long life and recyclable external thermal insulation systems which are very useful from the viewpoint of the conservation of energy and resources. However, from the viewpoint of resources circulation, they are very difficult to be done material recycling except for reuse as they are as panel components, because short-cut fibers are mixed dispersively in them. We should seek for the route to convert them into ecomaterials. This paper deals with ecomaterials design and ecomaterialization in short-cut fiber reinforced cement composites (FRC) by improvement of materials efficiency or resources productivity, by effective utilization of recycled or unused materials, paying special attention to the preservation of natural resources and the reduction of the environmental load.

2. ECOMATERIALS DESIGN[4)~6)]

When we want to use FRC in given elements of building and civil engineering structures in given environmental conditions, we need materials design and expert systems to judge which type of existing FRC should be selected and evaluated or how new type of FRC should be produced in order to satisfy the required and desired performances and functions. In these situations main three required performances in service in building field are structural, durability and fire– proof and –resistance ones (in civil engineering field the third one is not always required.) If we consider sustainable buildings and society taking into account the balance among the environment and economy and long service life / safety in the 21st century, we should establish ecomaterials design setting a new performance item of ecobalance such consumption of energy, low emission of CO_2 gas, and high materials efficiency.

Fig. 1 shows the schemes of this ecomaterials design. The point is the rational production, selection and evaluation of desired FRC by comparing four required performances with its performance data stocked in data base, and judging if satisfied performances are obtained when they are to be used, for example, in vertical walls of an office building in a fire-productive area in a sea side. As durability performance, we can set by the ratio of reduction of dynamic strength below 40% for ten years. As fire resistant and proofing performance, we set by the duration for half an hour against fire or semi-uninflamability. As structural performance, we can set the high flexural strength above $3.0 KN/mm^2$. Quantitative expression of these performances and establishment of calculation and evaluation methods of performances are needed as well as sophisticated database that we well established mainly as to dynamic characteristics.

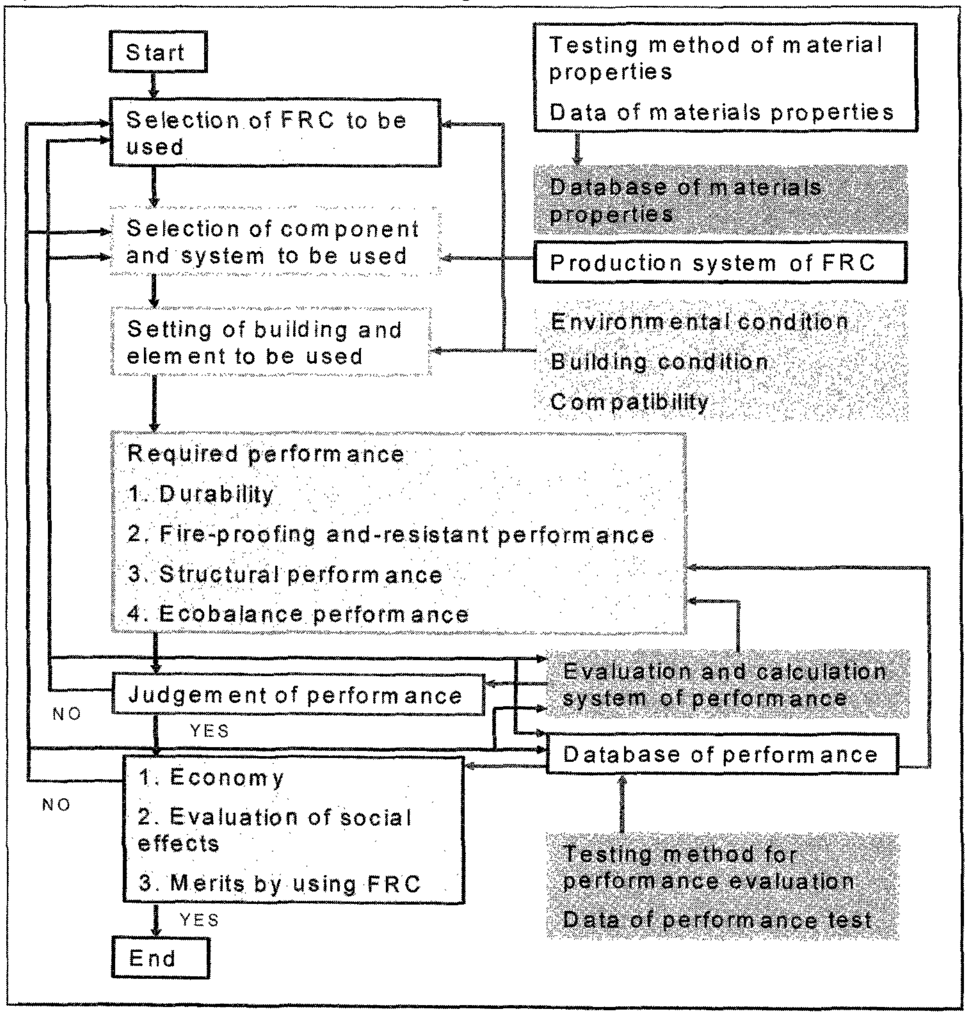

Fig.1 Concept of ecomaterials design of FRC

3. RESEARCH METHODS

In order to try to convert pitch-type carbon and alkali-resistant glass short-cut fiber reinforced cement composites (CFRC and GFRC (GFRC; conventional commercial nomination as GRC: we use this conventional nomination hereafter) into ecomaterials (that is, ecomaterialization), we carry out experimental studies about fundamental behaviors of CFRC and GRC by replacing virgin pure component materials with recycled materials, for example, replacing ordinary Portland cement and GRC cement (special cement modified as having low alkaline content for protection of glass fiber) with ecocement(recycled cement from urban waste), pulverized waste FRP powder as binder, and replacing river sand with recycled fine aggregate.

To what extent materials efficiency (or resources productivity) is improved by replacement of pure virgin materials with recycled ones are examined.

4. EXPERIMENT FOR CONVERSION OF PITCH- CFRC INTO ECOMATEIALS

4.1 Experimental methods

Materials: Types and properties of materials used in this experiment and their symbols are summarized in Table I.

(a) Cement

Two Types of cement, ordinary Portland cement (OPC) and low-chloride-ion-content type ecocement (EC) produced both by Taiheiyo Cement Co. Ltd. were used.

(b) Cement Replacing Binder

Pulverized powders of waste FRTS (glass fiber reinforced unsaturated polyester) (specific gravity = 1.77g/cm^3, and powder degree = 4,680 cm^2/g), produced by Nikka Plastic Co. Ltd. were used.

(c) Fine Aggregate

Two types of fine aggregate, pit sand (from Hamaoka-cho, Ogasa-gun, Shizuoka-ken, Japan) (specific gravity = 2.60, water – absorbing ratio = 1.72%, fines modulus = 2.87), and recycled sand were used.

(d) Fiber

Pitch type, general purpose class, carbon short – cut fibers (pitch-GPCF) (Kureca – chop C – 106S produced by Kureha Chemical Co. Ltd.) were used (fiber length = 6mm, specific gravity = 1.68g/cm^3, fiber tensile strength = 784 N/mm^2).

(e) Admixture

Two types of admixture, high performance water reducing reagent (Mighty 150: naphthalene sulfonic acid– formaline high – degree – condensed salt from Kao Co. Ltd.), and foam reducing reagent (Sunnopco SND 14HP powder polyester – type produced from Sunnopco Co. Ltd.) were used.

(f) Mixing Water

City tap water was used.

Table I Materials for pitch-CFRC and their properties

Materials	Properties	Symbol
Cement	**Ordinary portland cement** Specific gravity = 3.16 g/cm^3 , Surface area = 3,380 cm^2/g	*C(OCP)*
	Ecocement made from incinetated ash of municipal waste Specific gravity = 3.21 g/cm^3 , Surface area = 4,500 cm^2/g	*C(EC)*※
FRP Powder	**Pulverized powder of FRP** Specific gravity = 1.77 g/cm^3 , Surface area = 4,680 cm^2/g	*FRP*※
Fine Aggregates	**Pit sand** Specific gravity = 2.60 g/cm^3 , Water absorption = 1.71 % , F.M. = 2.88	*S*
	Recycled sand Specific gravity = 2.57 g/cm^3 , Water absorption = 2.26 % , F.M. = 2.87	*RS*※
Fiber	**Pitch-type , short cut carbon fiber** Fiber length = 6 mm , Specific gravity = 1.68 g/cm^3 , Tensile st. = 784 N/mm^2	*CF*
Admixture	**Superplasticizer** (naphthalene sulfonic acid)	*Ad1*
	Foam reducing agent (powder polyester)	*Ad2*
Water	**City tap water**	*W*

※ Recycled material

Table II Outline of preparation of CFRC

Mixing	mixer	**Omni-mixer** (mixing capacity : 5 litter)
	process	**<*C+S+RS+CF*> → hand mixing → <*W+Ad1+Ad2*> → Low speed during 30 sec. → High speed during 180 sec.** Mixing condition : 20℃ , R.H. 80% , 1 batch ; 3 litter
Curing	**Water curing in 20℃ for 26 days +Dry curing at 20℃ , R.H. 60% for 2 days**	

TableIII Mix proportions of pitch-CFRC using ecocement (EC) and ordinary Portland cement

Kind of Cement	W/ (C+FRP) wt.%	(S+RS)/ (C+FRP) wt.%	RS/ (S+RS) Vol.%	RS/ (S+RS) Vol.%	Ad1/C Wt.%	Ad2/C Wt.%	CF Vol.%
EC	40	25	0, 1, 3, 5, 10, 15, 20, 25, 30	0, 1, 3, 5, 10, 20, 30	1.0	0.1	1.0
OPC	40	25	0	0	1.0	0.1	1.0

Table IV Testing methods of fresh and hardened pitch-CFRC

Items	Specimen		Process
Flow value		———	***JIS R 5201***
Flexural St.	**Size :** **Number :** **Loading :**	**W ; 50mm × L ; 250mm × T ; 10mm** **6 specimens** **Span ; 200mm , centralize loading**	*Testing methods of* ***JGA***
Tensille St.	**Size :** **Number :** **Loading :**	**W ; 40mm × L ; 380mm × T ; 10mm** **6 specimens** **Distance ; 280mm , uniaxial tensile test**	*Testing methods of* ***JGA***

Preparation of Test Specimens: After mixing mortars by omni-mixer (from Chiyoda Giken Kogyo Co. Ltd.; nominal content = 5%), curing in water at 20℃for 28days was done. Afterwards, curing in constant temperature – humidity room at 20℃, R.H 80% for 2 days was done for test specimens. Table II shows the outline of preparation of CFRC. Table □shows the mix proportion of CFRC using ecocement and ordinary Portland cement.

Testing Methods: Based upon "Testing Methods of GRC" by Japan GRC Association, bending test (scale of test specimens; 50×250×100mm) and tensile test (scale of test specimens; 40×380×100mm) were done. Testing methods are summarized in Table IV.

4.2 Experimental Results

Fresh Behaviors: In Fig. 2 are shown the results of flow value test.

Flexural and Tensile Behaviors of Hardened Pitch-CFRC

Fig. 3 and Fig. 4 show the test results of flexural and tensile strength, respectively.

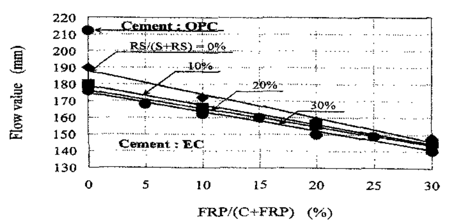

Fig. 2 Results of flow value test

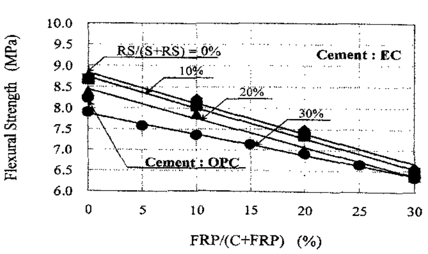

Fig. 3 Results of flexural strength

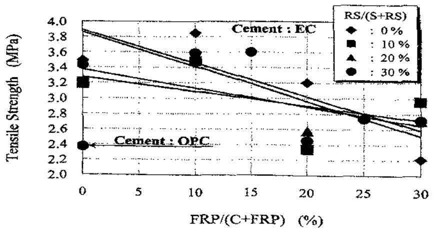

Fig. 4 Results of tensile strength

5. EXPERIMENT FOR CONVERSION OF G RC INTO ECOMATEIALS

5.1 Experimental methods

Materials: Types and properties of materials used in this experiment are almost the same as in experiment on conversion of pitch-CFRC into ecomaterials, expect for types of cement and fiber., and d only use of sea sand.

(a) Cement

Two Types of cement, GRC cement (GRC: specific gravity =2.97g/cm^3) and low chloride-ion-content type ecocement (EC) produced both by Taiheiyo Cement Co. Ltd. were used.

(b)Fiber

Alkali-resistant glass chopped strand (ACS 19PH -901X produced by Japan Electrochemical Glass Co. Ltd. (fiber length =19mm, fiber diameter = 18 μ , specific gravity = 2.40g/cm^3, fiber tensile strength = 2,450mm^2).

Preparation of test specimens and testing methods: Preparation of test specimens and testing methods are almost the same as in experiment on conversion of pitch-CFRC into ecomaterials, expect for the scales of test specimens of tensile and bending test as 40×380×30mm, 50×250×30mm, respectively.

5.2 Experimental Results

Fresh Behaviors: In Table V are shown the results of flow value test.

Results of flexural, tensile, and compressive tests of Hardened GRC: In Table VI are summarized the results of flexural tensile, and compressive test of hardened GRC. General aspects of flexural behaviors are shown in Fig. 5.

Relationships between the flexural strength of GRC using ecocement (EC) and GRC cement (GRC) and fiber content of glass fiber are shown in Fig. 6. Influences of replacement of EC and GRC with pulverized FRP Powder on flexural strength are shown in Fig.7.

6. Discussion

6.1 Improvement of Material Efficiency

In case of pitch- CFRC:

a) In comparison of behaviors of fresh pith – CFRC using eco – cement (EC – pitch – CFRC) with those using ordinary Portland cement (OPC – pitch CFRC), the former show better dispersion and material properties than the latter because of smaller powder ratio of ecocement. Flexural strength of EC – pitch – CFRC is rather greater than that of OPC – pitch CFRC.

b) Small effects of use of pulverized waste FRP powder and recycled sand were appreciated as the linear reduction of flexural and tensile strength with the ratios of replacement. However, they are almost comparable to the case of the only use of high purity, high quality virgin cement and aggregate.

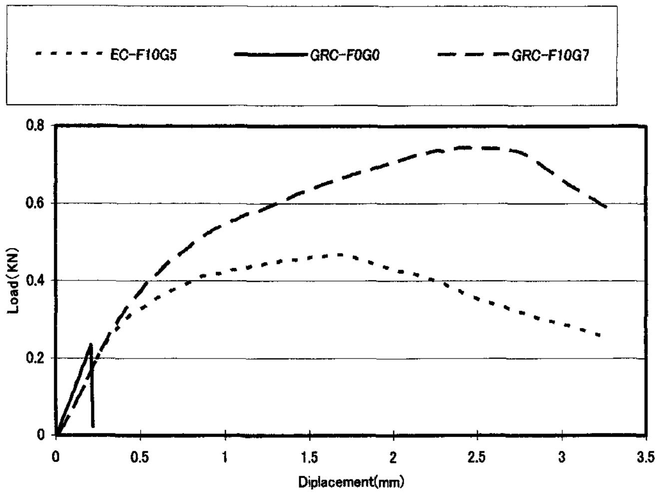

Fig. 5 General aspects of Bending Curves of GRC.

Table V Results of fresh GRC

Number of Test Specimens	Nomination of Test specimens	Natral flow value(mm)	Tapping flow value(mm)
①	EC-F0G0	171	-
②	EC-F0G3	174	4.14
③	EC-F0G5	170	242
④	EC-F0G7	157	193
⑤	EC-F5G3	165	156
⑥	EC-F10G0	184	246
⑦	EC-F10G3	156	-
⑧	EC-F10G5	157	233
⑨	EC-F10G7	149	192
⑩	EC-F15-G3	150	229
⑪	EC-F20-G3	133	223
⑫	GRC-F0G0	152	-
⑬	GRC-F0G3	147	247
⑭	GRC-F0G5	156	214
⑮	GRC-F10G3	127	146
⑯	GRC-F10G5	130	201
⑰	GRC-F10G7	124	163

EC: ecocement F: pulverized waste FRP powder
GRC:GRC cement G:glass fiber
FF10G5: conventional expression that the rate of replacement of pulverized waste FRP powder is 10%, and that content of glass fiber is 5%.

Table VI Results of flexural tensile , and compressive test of hardened GRC

Number of Test Specimens	Nomination of Test specimens	Tensile Strength (N/mm2)	Compressive Strength (N/mm2)	Flexural Strength (N/mm2)
①	EC-F0G0	2.4	2.62	2.62
②	EC-F0G3	4.14	10.6	10.6
③	EC-F0G5	3.3	15.8	15.8
④	EC-F0G7	3.6	20.1	20.1
⑤	EC-F5G3	3.91	4.35	4.35
⑥	EC-F10G0	1.37	15.7	15.7
⑦	EC-F10G3	3.86	17.8	17.8
⑧	EC-F10G5	5.68	16.5	16.5
⑨	EC-F10G7	3.41	13.4	13.4
⑩	EC-F15-G3	2.94	7.63	7.63
⑪	EC-F20-G3	4.42	5.99	5.99
⑫	GRC-F0G0	3.45	5.39	5.39
⑬	GRC-F0G3	5.18	10.2	10.2
⑭	GRC-F0G5	5.59	13.9	13.9
⑮	GRC-F10G3	3.86	8.05	8.05
⑯	GRC-F10G5	5.27	13.1	13.1
⑰	GRC-F10G7	5.09	20.7	20.7

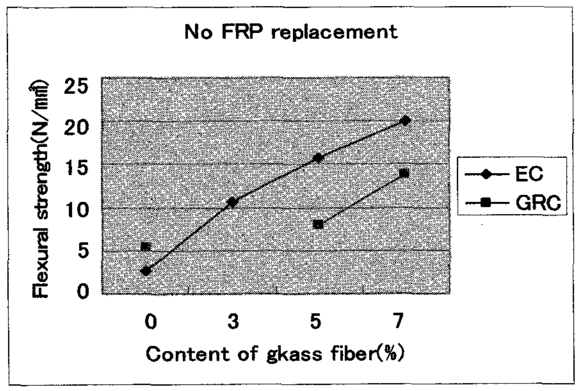

Fig.6 Relationships between the flexural strength of GRC using ecocement (EC) and GRC cement (GRC) and fiber content of glass fiber

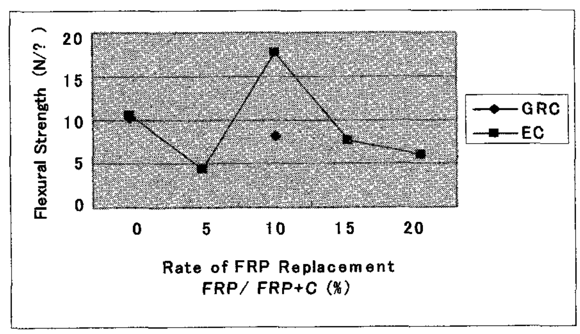

Fig.7 Influences of replacement of EC and GRC with pulverized FRP Powder on flexural strength (G3)

In case of GRC:

a) In comparison of behaviors of fresh GRC using eco – cement (EC – GRC) with those using GRC cement (GRC – GRC), the former show better dispersion and material properties than the latter because of smaller powder ratio of ecocement. Flexural strength of EC – GRC becomes greater with glass fiber content than that of GRC-GRC.

b) Clear effects of use of pulverized waste FRP powder and recycled sand were not appreciated probably because of interference between glass fiber and pulverized waste FRP powder . However, they are almost comparable to the case of the only use of high purity, high quality virgin cement and aggregate.

6.2 Evaluation Indicators of Ecobalance Performance

Materials Efficiency Indicator (MEI): If we reduce the use amount of virgin resources for demanded performances, for example, by using high performance materials with high specific strength and high elasticity, and by effective use of unused and recycled materials, we can reduce the environmental load. We can set this indicator as follows:

$$\text{Materials Efficiency (E)} = \frac{\text{Demanded Performance (DP)}}{\text{Total Use Amount of Virgin Resouces (TMR)}}$$

If performance P is reduced by p by using recycled materials replacing virgin materials by r, material efficiency can be calculated as follows:

$$\text{Materials Efficiency} = P\ (1-p)\ /\text{TMR}\ (1-r)$$

Considering experimental results of pitch-CFRC, materials efficiency is improved about 10% by using ecocement, and pulverized waste FRP as replacing material by 10% with ordinary Portland cement

6.3 Prediction / Evaluation Indicator of Recyclability

In Fig.6 is shown the concept of repeated partial recycling (cascade recycling) of FRC. The point is to consider the initial dynamic performance (P_o) and the ratio of the reduction of performance (r), and to do recycling several times until reaching the critical performance at least necessary in service (P_{cr}). For EC-CFRC, for example, P_o (Initial flexural strength) is 8.8KN/㎟ ^{2}. If we set P_{cr} as 3KN/㎟ ^{2} and as r as 20%.

$P_4 = P_o\,(1-r)^4 = 8.8\times(1-0.2)^4 = 3.2 \geqq 3$

Consequently, we can do repeated partial recycling about four times.

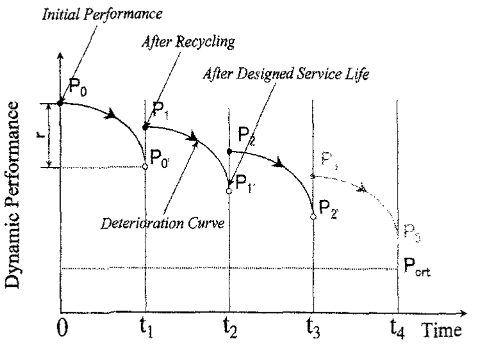

Fig.6 Concept of repeated partial recycling (cascade recycling)

7. CONCLUSION

Paying special attention to ecobalance performance including recyclability, we proposed the fundamental schemes of ecomaterials design of short-cut fiber reinforced cement composites (FRC) as the system of production, selection and evaluation of desired FRC corresponding to required performances of structural, durability, fire-proofing and –resistance and ecobalance. As concrete ecomaterials technology improving materials efficiency (or resources productivity). we tried to convert FRC into ecomaterials by examining experimentally the fundamental behaviors for fresh and hardened pitch-CFRC and GRC by effective use of recycled and unused resources, such as pulverized waste FRP powders and ecocement as cement replacing binder, and recycled sand. The following concluding remarks can be made:

(1) Material properties of these Pitch-CFRC and GRC using ecocement as recycled materials from urban waste were comparable to or rather improved compared with those of ordinary pitch- CFRC using ordinary Portland cement and ordinary GRC using GRC cement. These experimentally confirmed facts give us the route of effective resources circulation and ecomaterialization of FRC by effective use of recycled or unused materials.

(2) In case of pitch-CFRC, the linear reduction of flexural strength etc. with the ratio of replacement of ecocement with pulverized waste powder was observed, and within 5%, the flexural strength is not so reduced compared with ordinary -pitch-CFRC using ordinary Portland cement. In case of GRC, however, these clear effects were not observed. The interference of pulverized FRP powder(which is almost composed of glass particles with polymeric coating) with glass fiber are considered to be the main reason.

(3)Quantification of materials efficiency and recylability indicators were made successfully. .

7. ACKOWLEDGMENT

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