THE 'ENDEAVOUR' PROJECT
The chemical effects of microorganisms on fibre reinforced composite materials.

1. Introduction

Polypropylene (PP)/Polyethylene (PE) fibres have numerous properties that make them suitable for incorporation into many composite materials such as Fibre Reinforced Plastics (FRP) and concrete; low cost, ductility, ease of dispersal and are widely considered chemically inert; however, fibres can be degraded by microorganisms (1)(2)(3). The corrosive nature of biodeterioration on PP/PE fibers within FRP and concrete is not extensively documented.

The presence of PP/PE fibers within concrete Figure 1. delays the overall degradation process by lowering permeability, reducing the amount of shrinkage and expansion of concrete. This combination has proven to be a successful material in many types of structures, polymer fibres being used for structural purposes substituting partially or completely conventional steel reinforcement. Despite its widespread use, comparatively limited research has focused on the chemical effects of microorganisms on fibre reinforced marine concrete, and none have focused on identifying the mechanisms responsible for the effects and no published guidance is available.

Figure 1. Fibre concrete (Japan)
2. Background

Due to the non-polar nature of the PP/PE fibres, and their lower surface free energy, compared to cement paste, a gap is generated between the fibre and the cement matrix (4). In this void, moisture can permeate around the fibres, thereafter, following submersion; drying will facilitate disruptive microorganisms growing at the fibre/cement interface transition zone. As more and more fibres are exposed to hydrodynamic forces (whether tidal/rain impact, de-icing chemicals or power washing) and microbial forces, eventual liberation of fibres takes place, leaving many voids within the concrete. This in turn creates a more porous surface and a lack of water tightness. In this situation, the fibres having left the matrix do not increase toughness of the concrete as intended. Leading to an increase in permeability and paving the way for further deleterious chemical interactions between fibre and cement hydration products.

The author has compiled a comprehensive portfolio of research on the use of polymer fibres within concrete in a marine environment, over the last decade becoming a recognised authority within this field. In 2008 the author submitted a dissertation, An Investigation of Macro Synthetic Fibre Reinforced Concrete, as part of his BSc at the University of Central Lancashire UK. In the context of this new application, the proposed research will be named the 'Endeavour Project', the initial BSc research is referred to as Phase One. The work investigated the use of macro synthetic fibres in concrete, and its enhancement of concrete durability, as claimed by the producers of this relatively new fibre technology. The innovative research presented the results of an experimental investigation to determine the performance characteristics of macro synthetic fibre concrete (pictured below). Further details of this initial ground breaking fibre research may be found on the dedicated proposed project website 'Endeavour' at: http://fibrendeavour.weebly.com.

Phase 2 included PhD research partly carried out at the University of Fukui in Japan (5) (as part of a JSPS funded 2011 Summer Fellowship) investigated marine biofouling and its influence on the durability of fibre concrete sea defences using on-site and laboratory-based studies. The research investigated marine biofouling and its influence on the durability of fibre concrete sea defences using on-site and laboratory-based studies. The study was divided into three main phases namely: the surface analysis of armour concrete, the study of algal colonisation within the matrix and investigations into the presence of a bacterial biofilm within freshly hardened armour concrete. The effectiveness of photocatalytic coatings as a non-toxic anti-fouling strategy and cell attachment to synthetic fibres was also studied. It was found that algal growth quickly developed at the interface of inclusions within the matrix and that power washing with the use of Dairy Hypochlorite to remove this accelerated wear, leading to significant mass loss. It was also observed that bacterial growth within local beach sand, which was used in the production of the revetment armour units, survived the concrete manufacturing process. Bacteria were cultured from the sand and were found to match the Actinomycete like growth in the freshly hardened matrix of armour concrete. Further details of Phase Two fibre research may be found on the dedicated proposed project website 'Endeavour' at: http://fibrendeavour.weebly.com.

Phase Three, the Post-doctoral research programme; was undertaken at the University of Fukui, Frontier Fibre Technology and Science, Graduate School of Engineering, Japan. The impact of sodium hypochlorite on polypropylene fibre reinforced concrete (6)(7) was studied. The absence of available site data on the durability and performance of marine concrete, with polypropylene fibre inclusions was a fundamental issue justifying this study. This research investigated the use of sodium hypochlorite (NaClO) and described the
effects of this destructive chemical upon the innovative use of polypropylene fibres within a marine concrete matrix. Modifications in visual, chemical and structural properties of the polymer were evaluated by attenuated total reflectance Fourier transform infrared spectroscopy and scanning electron microscopy with energy dispersive X-ray analysis. Further details of Phase Three of the fibre research may be found on the dedicated proposed project website ‘Endeavour’ at: http://fibrendeavour.weebly.com.

3. Proposed New Research

This research (Phase Four) investigates and describes the chemical effects of microorganisms upon the innovative use of polypropylene fibres within a concrete matrix. Polypropylene/Polyethylene fibres will be treated with microorganisms (bacteria and Algae) replicating site conditions. Modifications in visual, chemical and structural properties of the polymer will be evaluated by attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR) (Thermo Scientific 105 Nicolet 6700 Continuum), and scanning electron microscopy (SEM) with energy dispersive X-ray analysis (EDX). Analysis of ATR-FTIR spectra of the untreated and treated samples will reveal any chemical alterations to the material. SEM observations will confirm physical fibre degradation, the fibre durability and performance. As a result, the visible, structural and chemical properties of the fibre will be comprehensively reported when exposed to microorganisms.

The constituents of matter and the basic phenomena involving them, are all interconnected; that they cannot be understood as isolated entities but only as integral parts of a unified whole (8). The qualitative predictive capabilities of a holistic model, using in situ investigations was successfully demonstrated by Basheer (9) and will be further developed in this proposed research. A holistic approach based on the principle that strength through durability, rather than durability through strength was offered by Swamy (10) underlining the need for holistic design, with a global approach to all aspects of fibre concrete technology.

There is an accumulative awareness of the significance of a holistic approach towards material durability, study and site practice. A holistic model will be presented, as part of this research detailing the transportation, chemical alterations and degradation process of micro synthetic fibres due to microorganisms. Microscopic investigations of study site fibre concrete will used to validate the model. This multidisciplinary study will be the first to report the chemical composition, attachment, interaction and growth of microorganisms upon synthetic fibres within concrete, laying the foundation for more research into this phenomenon.

A more thorough perception of biodeterioration, offered in this research, will be realized by developing a ‘ordered biodeterioration,’ a biodeterioration that perceives the outcomes of such attachment and growth as an organic system rather than a single degradation mechanism. It is the advancement of this concept that forms the philosophy of this proposed investigation. By adopting the holistic approach, the model offers a more complete understanding of consequences of the biodeterioration of synthetic fibres. It exemplifies the growth of biodeterioration on synthetic fibres, within their aquatic environment, offering a systematic explanation of the unreported damage caused by biodeterioration. The model, an analysis of synthetic fibre performance, is based on four elements, each element, in turn, can be related to numerous causes, for instance, the loss of material could be also be accelerated by impact, washing, use of de-icing materials and microbial filamentous growth. Theoretically the degradation can be reduced or prevented by controlling at least one of the elements. The model presented will give designers of
future composite materials a new understanding as to how concrete can degrade when subjected to biodeterioration. Furthermore such a model can be used to assess existing structures, assisting in the clarification of augmented degradation of fibre-reinforced marine concrete.

The overall aim of this study is to examine and report the changes that may occur on synthetic fibre properties due to biodeterioration.

The term inert used to describe a material that is not chemically reactive is often wrongly used to describe PP/PE, and fibre manufacturers, mistakenly, often label their products having a high resistance to alkali, acid and salt. With PP/PE fibre reinforced concrete becoming more and more prevalent in Japan the use of fibre concrete and FRP's needs further attention. Guidance is required on the use of such materials to enable authorities to make informed choices of appropriate and material friendly maintenance programs.

To successfully meet the needs of the future, the whole process of “fibre concrete technology’ should be contemplated within a holistic approach, and a system concept implemented. Systems design can be expressed as a process of selecting, combining, and developing the components both materials and procedures, to produce a system that will ultimately fulfil the designed objectives. Durability, in this sense, indicates a system, a well maintained concrete structure that achieves its optimum level of designed performance using environment and structurally friendly practices. The knowledge of biodeterioration, affecting the fibres, enables a more accurate quantification of the deterioration of marine concrete or any composite material. When our structures prematurely fail and no longer serves its purpose, it will be classified as ineffectual, regardless of what caused the failure, degradation of fibres, biodeterioration, poor design, unsuitable materials, poor workmanship, powerwashing or a combination of these. The entire system failed. For the global concrete/polymer industry, which includes design engineers, stakeholders, material manufacturers, and maintenance contractors; in order to successfully meet the needs of our future marine structures, the entire process of concrete degradation should be considered and a systems concept adopted.

4. Deliverables

• Three International Journal Papers will be published.

• Three European Articles will be published.

• One presentation at a Japanese Conference will be undertaken.

• A Project ‘Endeavour’ website has been constructed and will feature experiments, results, discussion and project news etc.

http://fibrendeavour.weebly.com/

• A Project ‘Endeavour’ Newsletter will be circulated quarterly and downloadable from the project website. Interested parties have expressed an interest in being updated about the project including Japan, UK, USA, Europe, Russia and India. These Newsletters will be collated to form a project Endeavour e-Journal on conclusion of the project, available for free global circulation.
5. Conclusion

A holistic led approach adopted within this project investigating polymer durability ensures that no part of the system is overlooked and takes into account the concurrent interaction of many factors and the consequent changes occurring in a composite material. A shift in the science of polymer durability from a reductionist to holistic approach is also necessary before one can develop more accurate systematic test methods, maintenance specifications and relevant codes that are truly applicable to the durability of our structures. Absence of the holistic system concept in designing, manufacture and maintenance of composite materials is clearly demonstrated in the current global examples of early degradation featured in previous research by the author.

7. References


