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An assessment of the commercial prospects for fibre- and polymer-modified concretes*

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Dr Pomeroy has been pragmatic in his assessment of the probable avenues along which commercial exploitation of the research findings available concerning Portland cement systems strengthened by micro-reinforcement in the form of fibres and polymers may be possible. It is true that these materials would be uncompetitive where the use of traditional reinforced concrete is well established. However, where conventional reinforced concrete has often been found to be inadequate or where it cannot be used at all, fibre- and polymer-modified concretes have a definite role to play. Such special applications apart, these micro-structure-strengthened concretes can also serve as competitive replacements of products made of other materials.

An application in this vein is the fibre-reinforced concrete manhole cover, which competitively and effectively replaces the traditional cast-iron product. Dr Pomeroy says that this is unfortunately the sole large-scale commercial exploitation of fibre-reinforced concretes reported to date. Another application which may be in the offing is the replacement of the traditional asbestos-cement products by glass-reinforced cement (grc), a replacement prompted not by economics but on health grounds.

Dr Pomeroy rightly deplores the proselytizing claims made of significant properties purported to be unique for fibre- and polymer-reinforced concretes which have unfortunately been made by some enthusiasts. He also finds most of the papers presented in 1975 RILEM Symposium academic. I feel that this is a hypercriticism, not because I happened to contribute a paper to the symposium but because, if there were no papers reporting basic researches even in a first international conference on a theme, this would only help the complete ossification of its development.

Dr Pomeroy also calls for a complete ban on future research into fibre- and polymer-modified concretes so as to concentrate on commercial exploitation. Although, in future, discretion may be needed in choosing a research project in these areas. I feel that to ostracize research effort completely is dangerous to a healthy development, in as much as even the so-called 'band-wagon' phenomenon does not seem to be in sight in these areas, thanks to cost considerations and the limited availability of the fibres.

In my view research is, in fact, needed to find out how effectively fibre micro-reinforcement could be used in harmony with traditional bar micro-reinforcement to avoid some of the shortcomings of traditional reinforced concrete. The use of fibres in reinforced concrete structures subjected to concentrated loads, combined stresses and dynamic loading must be explored.

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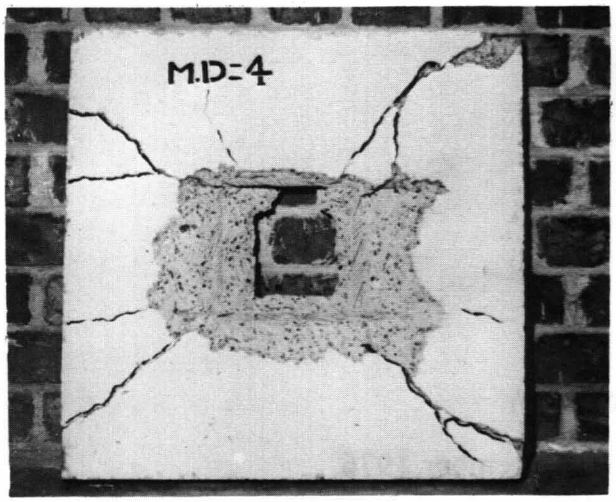

Figure I: Bottom of a reinforced concrete slab subjected to a central concentrated load.

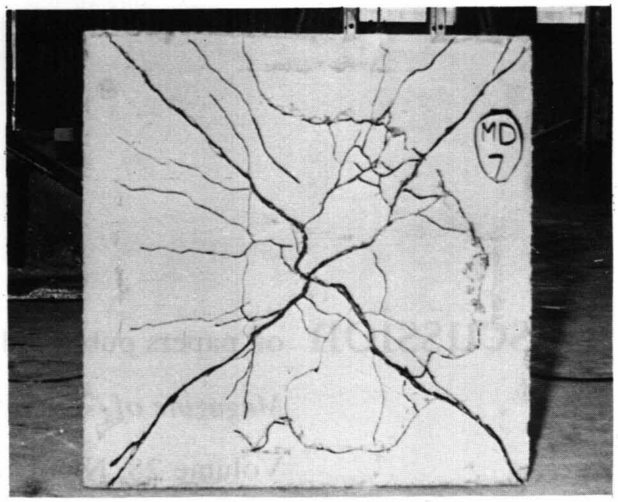

Figure III: Flexural failure of the slab obtained by the addition of steel micro-reinforcement.

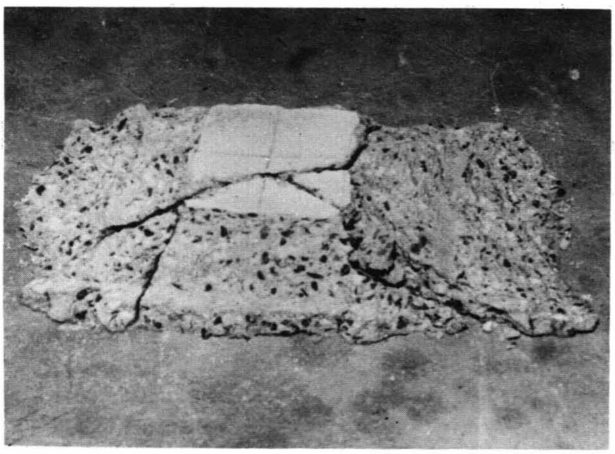

Figure II: The pyramid of concrete punched out of the slab.

As an example, I would like to quote the remarkable improvements in performance imparted by the ubiquitous presence of fibres to the mass of a reinforced concrete slab which I tested under a central concentrated load. Figure I shows the failure pattern of the bar-reinforced slab 600 mm square, simply supported on all sides, subjected to a central concentrated load over an area of 100 mm square. By using established theories, the punching strength and the flexural strength were estimated as 52·80 kN and 77·97 kN respectively. The slab failed in punching, as indicated by the failure load of 49 65 kN and by the pyramidal failure shown in Figure II. Incorporation of steel fibres in the slab gave an ultimate load of 81·92 kN.

The conclusion is that the presence of fibres, by augmenting the shear strength, helps to mobilize the full flexural strength of the bar reinforcement and retard the incipient punching failure. This is evident from the value of the ultimate load and from the failure pattern shown in Figure III, which indicates well developed yield lines. The fibres, in addition, enhance the cracking load of the slab and, by developing anti-splitting characteristics, impart substantial assurance towards the integrity of the structure against unexpected impacts. These findings could be used profitably in applications like manhole covers and drainage gratings, flat-plate floors and footings.

The use of high-strength steel as bar reinforcement in reinforced concrete is another area in which steel micro-reinforcement can be profitably deployed in association with macro-reinforcement. It is well-known fact that, in traditional reinforced concrete, high-strength bars cannot be used owing to cracking considerations. Yet the use of high-strength steel would result in considerable economy[1]. A way of using high-strength steel bars as reinforcement in concrete has been suggested[1] but this technique, though remarkably good, is suspect on grounds of fire resistance[2, 3].

Another area which is in its infancy is full and semi-sandwich construction, wherein plate reinforcements are used to create a sandwich with a concrete filling. The ultimate strength of these elements has been reported to be controlled by shear–tension failures[4, 5]. Improvements might perhaps result from the use of steel fibres in the filling of such sandwiches.

A similar idea involving a reinforced-concrete –fibre-reinforced-skin sandwich has been suggested by Dr Pomeroy as one of the possible commercial applications. He also rightly points out the need to concentrate on the commercial exploitation of the ease of formability of thin fibre-reinforced products by evolving suitable production techniques such as extrusion. In fact, the feasibility of this has been recently reported by Zollo[6] in the USA.

Contribution by K. Ganesh Babu and B. V. Subrahmanyam
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In comparison with conventional concrete, fibre-reinforced concretes offer improvement in ductility, impact and fatigue resistance, and flexural strength. Polymer-modified concretes offer considerable improvements in strength, resistance to chemical attack, to abrasion and to fatigue, and impermeability. Very little information is available about the commercial applicability of these new materials. Dr Pomeroy is to be congratulated for his timely paper bridging this gap. He has rightly chosen to discuss fibre- and polymer-modified concretes together, as they have complementary properties.

It is true, as Dr Pomeroy observes, that fibre-reinforced concrete cannot replace ordinary concrete in conventional applications. However, the different fibres that are available, together with their increased energy absorption, crack restraint, and impact and fatigue resistance will certainly make fibre-reinforced concrete useful for special applications such as piles, manhole covers, airfield runway overlays, spillways, bridge decks, tunnel linings, refractories, etc.[7]. The major problem appears to be the lack of adequate knowledge for the design of fibre-reinforced concrete mixes. Fundamental studies on the microscopic and macroscopic properties are also essential.

As far as polymer-impregnated concrete is concerned, Dr Pomeroy considers that the different operations involved are really suitable only for a precast concrete factory. However, these techniques have been suitably modified for field applications, notably bridge decks[8] and spillways[9].

Dr Pomeroy feels that very-high-strength concretes (100 N/mm^2) can be produced conventionally and that therefore there is little advantage in going for polymer-impregnated concretes (120–150 N/mm^2). However, it must be appreciated that conventional concretes with compressive strengths of the order of 100 N/mm^2 cannot be produced except with stringent controls on materials, workability and supervision. As against this, even ordinary concretes with strengths of 20 N/mm^2 can be improved to 100–150 N/mm^2 by relatively simple impregnation procedures.

The limited information there is about the creep of polymer-impregnated concrete indicates that it has a lower creep rate than corresponding unmodified concrete. By a proper use of copolymer in impregnation, it has been proved that high strengths with sufficient ductility can be obtained[10]. Therefore not all polymer-impregnated concretes are brittle: ductile, yet strong polymer-impregnated concretes can be produced.

There have been a number of commercial applications, notably for piles in Japan, bridge decks and spillways in USA and ferrocement units in South Africa. The qualities like resistance to chemicals, to cycles of freezing and thawing and to heavy abrasion offer vast scope for the commercial exploitation of polymer-impregnated concrete.

Dr Pomeroy's contention that improvement of strength in the case of polymer–cement concrete is only due to the reduction in water content is questionable. On the basis of scanning-electron-microscope observations, Isenburg et al.[11, 12] have concluded that, besides giving fluidity to the mix, the polymer forms an interpenetrating network. This network arrests the formation and propagation of microcracks. Thus the polymer admixtures, apart from reducing water/cement ratio, participate in and reinforce the behaviour of the matrix.

An important area of application overlooked by Dr Pomeroy for the application of polymer-impregnated and polymer-cement concretes is related to their improved impermeability.

There is, as Dr Pomeroy has said, a need for further research regarding the use of super-plasticizers.

In conclusion we feel that there is no unique combination of these new materials that can answer the needs of all problems. Each application requires a specific property for which one or other of these new materials can definitely be used to advantage. It has, however, to be remembered that the cost of polymers is relatively high and hence the applications will be limited to special situations. Instead of viewing these materials merely as being of limited value for conventional applications, structural engineers must take up the challenge to explore new avenues for their application which utilize those of their advantageous properties that are particularly beneficial.

Reply by the author

The fact that Mr Krishnaiyengar Rajagopalan, Dr Ganesh Babu and Dr Subrahmanyam have responded to my paper on fibre- and polymer-modified concretes in the way that they have has convinced me that such a paper was timely in that it has made workers examine their objectives more carefully before embarking on a new research programme than they might otherwise have done.

Of course, I was aware of the various applications mentioned by the writers, but the evidence that I have regarding *economic* use of these modified materials is far less encouraging than their contributions imply. Evidence that a particular technique can provide a product with an adequate structural performance does not automatically mean that the technique is the best choice for the application. A gold-plated tap could function perfectly satisfactorily, but this does not mean all taps should be gold-plated.

I am sorry that Mr Rajagoplan thought I favoured a complete embargo on research on these materials. Far from it but, in order to establish the areas that merit study in greater depth than hitherto, it is essential to design, manufacture and use fibre and polymer concretes for special applications. I consider that the punching tests cited form part of a development programme aimed at a particular requirement and certain advantages are claimed by the writer. It must be remembered, though, that steel fibres add considerably to the cost of the concrete and it should be verified that, if the extra expenditure had been directed to different *conventional* reinforcement, the enhancement of strength would not have been even greater.

The same argument can be levelled against the use of fibre concrete round high-strength steel bars. The designer wants to know whether the extra cost of the steel fibres is justified. Would additional steel in the form of stirrups, for example, give a better and cheaper solution? At present it is difficult to provide the answer, because not only material costs must be considered but also the cost of fabrication, and this can only be assessed for a specific application.

Despite the understandable alarm about the use of asbestos fibres, the cost disadvantage of alkali-resistant glass fibres is so great at the present time that replacement of asbestos–cement sheeting will only result from strong political pressure, and this will be tempered by economic considerations. However, there are many interesting grc developments, as I pointed out, the glass fibres being used primarily as a fabrication aid that permits methods and forms of construction that would not otherwise be possible. I still believe the prime effort that is needed is in seeking the right applications for fibre-modified concretes and exploiting our existing knowledge. This may well be followed by an increased demand for research in certain areas.

With regard to polymer concretes, I do not think one should reject the concept of high-strength concretes made from ordinary Portland cement and good-quality aggregates on the grounds that close supervision and quality control would be necessary and suggest that it would be better to make poor-quality concrete and then spend very large sums of money on upgrading the concrete by polymer impregnation.

I agree with Dr Babu and Dr Subrahamanyam that I over-simplified the mechanism of strength development consequent upon the incorporation of a polymer emulsion in the mix, but the results of our own work[13] have shown that the compressive strength of a polymer–Portland-cement concrete is dominated more by the water/cement ratio than by the polymer content, but that the tensile strength of the concretes was sensitive both to the water/cement ratio and to the polymer content. However, it is pointed out in the paper that, to achieve a target tensile strength, it is more economic to use the minimum polymer content by reducing the water content as much as possible.

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