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Durability of Hybrid Polypropylene–Glass Fibre Cement Corrugated Sheets

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Abstract

Two types of fibre cement corrugated roofing sheets, one being a hybrid containing fibrillated polypropylene networks and alkali resistant glass fibres, and the other reinforced solely by the fibrillated polypropylene networks, have been exposed to natural weather for six and ten years, respectively. Flexural test results indicate that, for these exposure periods, the strength and toughness for both types of sheets has been little affected. A 20% increase in flexural peak load was found for the hybrid polypropylene–glass fibre cement sheets. *© 1998 Elsevier Science Ltd. All rights reserved.*

Keywords: Fibrillated polypropylene networks; glass fibres; hybrid sheets; PP sheets; natural weathering; load–deflection curves; durability

INTRODUCTION

The concept of utilising layers of fibrillated polypropylene film, opened up to form networks, to fabricate fibre cement thin sheeting was developed by the University of Surrey in the late 1970s[1,2]. The use of networks of fibrillated polypropylene film can yield a composite with high energy absorbing capacity, compared with other fibre cement sheet materials available in the market.

In order to manufacture the material in large volumes, an industrial process, the Reticem† process, in which fibrillated polypropylene networks are fabricated into a semi-dry cement matrix with subsequent vacuum dewatering, was developed[3]. Sheets manufactured in the process for roofing and cladding were put on the Italian market in 1987 under the trade name 'Reticem'.

In 1988 a more advanced industrial process, the Retiver‡ process[4,5], was developed. The Retiver process utilises both continuous and chopped alkali resistant (AR) glass fibres in addition to the fibrillated polypropylene networks. The corrugated Retiver roofing sheets have been marketed in Italy since 1989.

It has been shown[4–7] that, by the hybrid use of fibrillated polypropylene networks and AR-glass fibres, the resulting composite yields substantial improvements in mechanical properties compared with their individual fibre cements. In particular, the strain at the completion of matrix multiple cracking and the crack widths within the multiple cracking region are much smaller for the polypropylene–glass hybrid compared with those of the all-polypropylene composites. The strain at which the glass fibres maintain their maximum stress can be considerably increased by the presence of polypropylene networks leading to a much higher load bearing capacity, up to 1.5% strain, than either of the individual systems alone or of the sum of their components. At peak load,

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where the glass fibre fails in the hybrid, the hybrid sheets do not break and a substantial load is continuously sustained by the high elongation polypropylene networks which significantly increases the composite toughness to resist impact. The presence of one fibre enables the reinforcing potential of another fibre to be more efficiently utilised.

All newly developed fibre reinforced cements for roofing and cladding require real time durability testing before market credibility can be achieved. Hannant[8] and Majumdar[9] have published real time data of flat coupon specimens on polypropylene and glass cements up to 10 and 20 year, respectively. Results reported by Hannant[8] indicate that there has been little change in the strength and ductility of the polypropylene films during a 10-year natural weathering scale. The weathering characteristics of AR-glass fibre cement composites are much more complex because they depend on matrix alkalinity, on surface treatment of the fibres, on interfacial microstructure between the two phases, and on the weather conditions to which they are exposed. In the past there has been a loss of strength and ductility of glass fibres in high alkali cement matrices with time particularly when they are exposed in a damp or wet environment. However, recent papers on accelerated testing[10–12] have demonstrated considerably improved durability provided that the correct matrix formulations are used.

In this paper, real weathering results for up to six years of the corrugated Retiver sheet (hereafter called the 'hybrid sheet'), and up to ten years of the corrugated Reticem sheet (hereafter called the 'PP sheet'), are reported. Both types of sheet had served as roofs on buildings and hence were exposed to natural weather before testing.

SPECIMENS AND TEST DETAILS

Corrugated PP sheets and hybrid sheets were installed as garage roofs exposed to natural weather in Broni one month after the start of commercial production. At 4 and 6 year for the hybrid sheets, and 8 and 10 year for the PP sheets, some of the aged sheets were removed from the garage roofs and their flexural properties in terms of flexural peak load and toughness were assessed, compared with the results at one month of the same product. The sheets used in this weathering programme had a profile of 177/51 (Fig. 1) i.e. 177 mm pitch length and 51 mm height of corrugations, and a dimension of 1220–2130 mm long by 920 mm wide. The sheet thickness ranged from 6.0 to 8.0 mm.

Two types of hybrid sheets, here named Hybrid I and Hybrid II, were used in the test and their reinforcing structures as flat sheets are shown in Fig. 2. Hybrid I [Fig. 2(a)] contained three packs of fibrillated polypropylene networks, one layer of chopped glass strands, randomly distributed in the two dimensional plane, and continuous glass rovings which were arranged longitudinally with seven rovings in each trough corrugation near the tensile surface and three rovings in each crest corrugation.

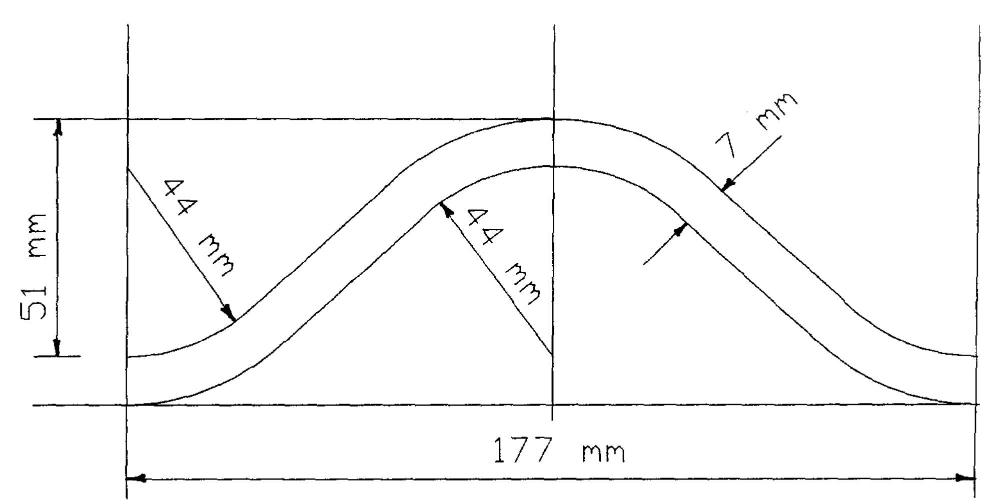

Fig. 1. Profile 177/51 of corrugated fibre cement sheets.

Hybrid II [Fig. 2(b)] contained three packs of polypropylene networks and two layers of chopped glass strands without continuous glass rovings. The PP sheet consisted of solely four packs of fibrillated networks. Detailed information concerning the fibres can be seen elsewhere[6] but below a very brief description is given.

The industrial product of fibrillated polypropylene networks (Retiflex) consisted of 12 layers of opened networks for each pack, eight being in the longitudinal direction and four at right angles to this. The continuous glass rovings consisted of 32 strands per roving with about 200 filaments per strand. Chopped glass strands of about 38 mm length were cut from the continuous glass rovings during fabrication. The matrix used in the trial productions mainly consisted of Type 425 Portland cement and silica sand with a sand-to-cement ratio of about 0.38, although several modifications have been made on the matrix and the reinforcement since then. The flexural test on a complete corrugated sheet was carried out by three-point loading under a 1100 mm clear span using a set-up complying to prEN 494[13].

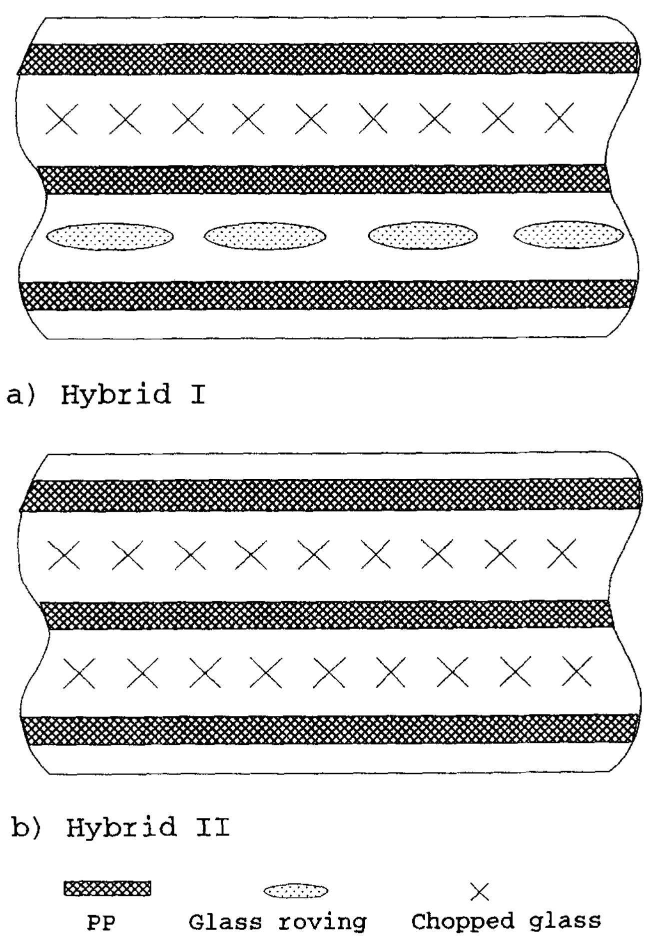

Fig. 2. Reinforcing structure of two types of hybrid polypropylene– glass fibre cement corrugated sheets used in the aging programme.

It was observed during the tests that both the hybrid sheet and the PP sheet did not break into halves at peak load. This is one of the fundamental differences between the polypropylene-network-containing sheets and the other fibre cement sheeting materials.

From the recorded load–deflection data and the plotted load–deflection curves, important values, i.e. the limit of proportionality (LOP), the peak load and its corresponding deflection, and the toughness, or energy absorbing ability, of the sheets were determined. The LOP was assessed from the point where the load–deflection curve visually started to depart from linearity. The toughness was determined from the total area under the load–deflection curve up to the peak load.

RESULTS AND DISCUSSION

Hybrid sheets up to 6-year natural weathering

Figures 3 and 4 show representative load–deflection curves of the corrugated Hybrid I and II sheets at 4 and 6 year, respectively. The similarity in the curve shapes of an identical sheet type implies that a period of two year's further weathering (from 4 to 6 year) had little effect on the performance of the products. The load–deflection curve was linear prior to about 3.4 kN m^{-1} sheet width. Hereafter the load at a given deflection was greater for Hybrid I sheet (Fig. 3) which contained continuous aligned glass rovings giving a greater reinforcing efficiency compared with the short glass strands.

Important data are summarised in Table 1 indicating that, up to an exposure period of 6 year, both Hybrid I and II sheets had no sign of reduction either in peak load or in extension (toughness). Instead there has been an increase of about 20% in peak load, compared with the results at one month of the same product. For instance, the average peak load of Hybrid I sheets was about 7400 N m^{-1} at one month corresponding to an average deflection of 42 mm (Table 1). The peak load had increased to 9200 N m^{-1} (about 28 MPa) at 41 mm at 6 year, however. Thus, there was no evidence of alkali attack on the glass fibres which shows that

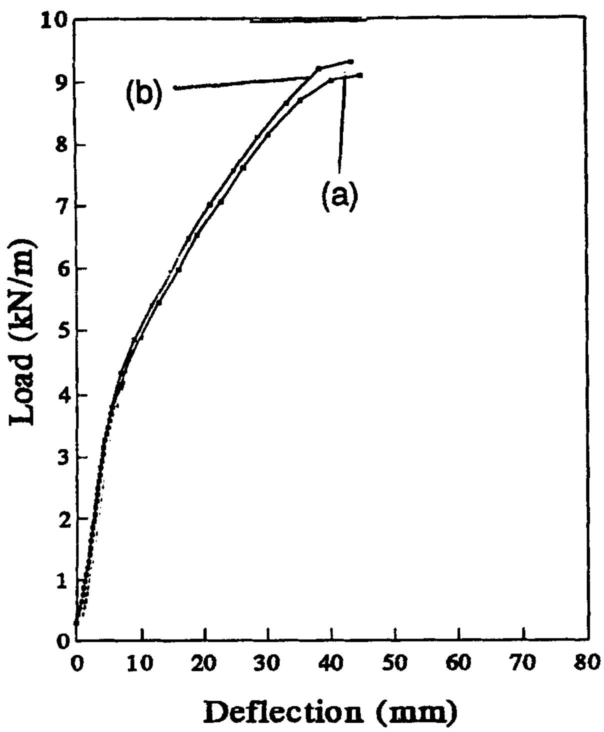

Fig. 3. Load–deflection curves of Hybrid I corrugated sheets [Fig. 2(a)] exposed in natural weather for 4–6 year. Fibre combination: PP+glass roving+chopped glass strands. Sheet thickness = 7.5 mm. (a) 4-year exposure; (b) 6-year exposure.

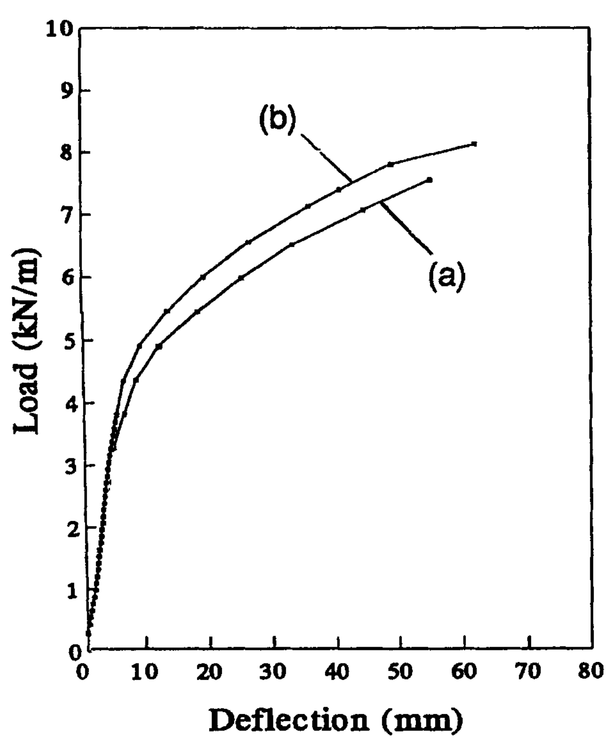

Fig. 4. Load–deflection curves of Hybrid 2 corrugated sheets [Fig. 2(b)] exposed in natural weather for 4–6 year. Fibre combination: PP+chopped glass strands. Sheet thickness = 7.5 mm. (a) 4-year exposure; (b) 6-year exposure.

Table 1. Average flexural results of corrugated hybrid sheets (Profile: 177/51) up to 6-year natural weathering (three-point loading, 1100 mm span)

	1 month*	4-year†	6-year‡
Hybrid I			
LOP (kN m^{-1})	/	3.4	3.5
Peak load (kN m^{-1})	7.42	9.13	9.20
Deflection at peak load (mm)	42	40	41
Sheet thickness (mm)	8.0	7.6	7.4
Hybrid II			
LOP (kN m^{-1})	/	3.2	3.3
Peak load (kN m^{-1})	6.20	7.49	7.65
Deflection at peak load (mm)	68	65	69
Sheet thickness (mm)	8.1	7.7	7.5

*6 sheets used for each type. LOP value is not available — only peak load and deflection were recorded.
†2 sheets used for each type.
‡4 sheets used for each type.

the improved treatments are effective on a six year timescale.

The toughness, or energy absorbing ability, of fibre cement materials is frequently assessed by measuring the area under the load and displacement curves. Hibbert and Hannant[14] demonstrated, by measuring the area under the stress–strain curves in direct tension, that the use of layers of networks of fibrillated polypropylene film in cement produces composite materials which have a high energy absorption to failure compared with other fibre cement sheet materials. This finding is also confirmed by the flexural test results on the corrugated sheets of the present research. At 6 year, the notional energy measured at the peak load under the load–deflection curve of one Hybrid I sheet (Fig. 3) is 290 kN.mm, and that of one Hybrid II sheet (Fig. 4) is about 380 kN.mm, compared with about 30 kN.mm for an asbestos cement sheet, about 50 kN.mm for a compressed and autoclaved cellulose cement sheet, and about 340 kN.mm for a fresh (i.e. un-aged) hybrid sheet of a recent production. The latter three energy values are measured from the load–deflection curves shown in Fig. 5 for similar sheet dimensions tested under the same conditions. The high toughness for the hybrid sheets, mainly attributed to the reinforcement by the fibrillated polypropylene networks assisted by the continuous glass rovings, is of benefit in dynamic loading situations such as the impact of large hailstones as occurred in the

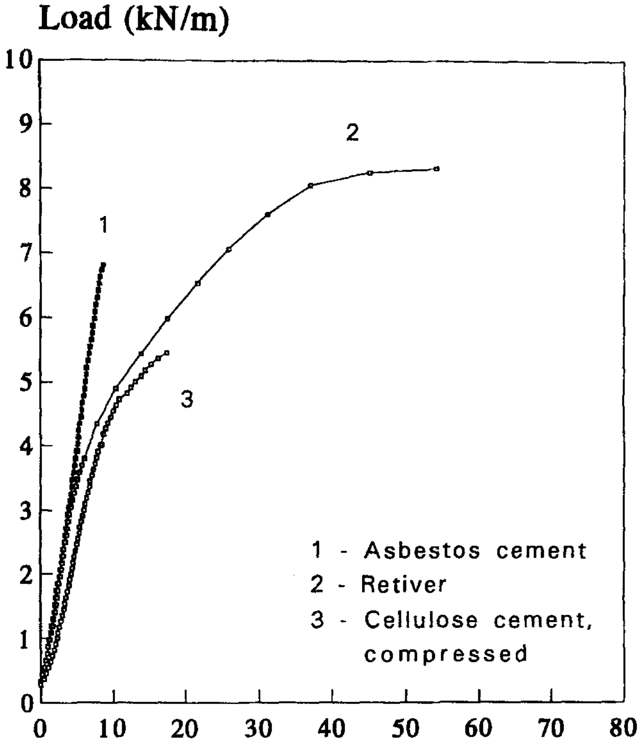

Fig. 5. Load–deflection curves of unaged fibre-cement corrugated sheets. Three-point loading, 1100 mm span, tested at wet condition, 6.5 mm sheet thickness.

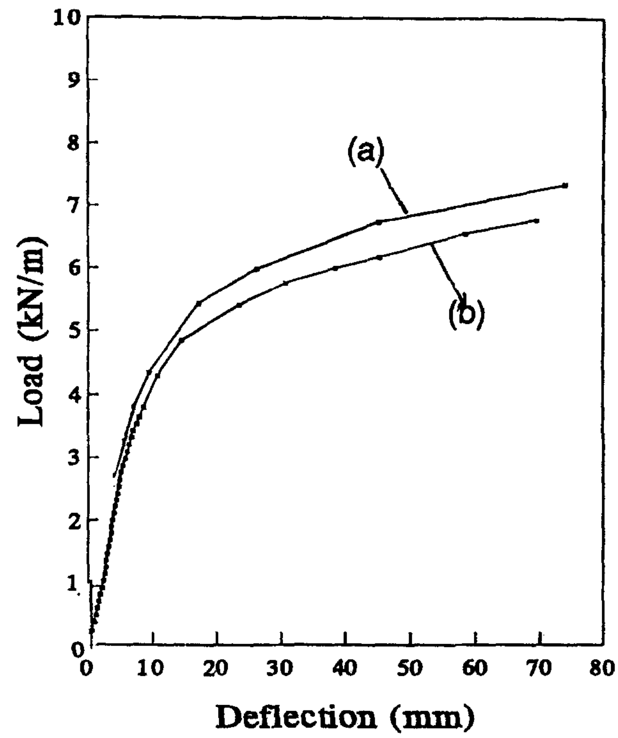

Fig. 6. Load–deflection curves of fibrillated polypropylene networks reinforced cement corrugated sheets (Reticem) exposed in natural weather for 8–10 year. (a) 8-year exposure, 6.7 mm sheet thickness; (b) 10-year exposure, 6.2 mm sheet thickness.

severe hailstorm in northern Italy in July 1993[15]. Holes were punched straight through the asbestos cement sheets by the hailstones but there was no visible damage to the hybrid sheets. The exceptional energy absorbing ability of the hybrid polypropylene–glass fibre cement sheets was clearly shown.

PP sheets up to 10-year natural weathering

Figure 6 shows the load–deflection curves of the aged corrugated PP sheets at 8 and 10 year. In Table 2 typical data are included. It is seen that the LOP of PP sheets (Fig. 6) after an exposure period of 8 or 10 year, had become equivalent to that of the hybrid sheets (Figs 3–5), probably because of the continuing hydration and carbonation of the cement matrix. The load bearing capacity of the PP sheet after LOP however, was smaller than that of the hybrid sheets which contained high elastic modulus glass fibres. The improved load bearing capacity particularly at the small deflections typical in service is one of the major advantages of the hybrid sheets compared to the PP sheets.

It can be seen from Table 2 that the peak load of the PP sheets, about 7.2 kN m^{-1} at 75 mm, was little changed by a period of 8 year's exposure in natural weathering. The peak load at 10 year was apparently smaller but this is caused by the smaller sheet thickness. The toughness for a 10-year PP sheet (Fig. 6) was about 370 kN.mm, apparently greater than that of a hybrid sheet (290 kN.mm, Fig. 4) containing glass rovings. However, it should be borne in mind that the toughness of the sheets was calculated from a 'peak load' criteria and that

Table 2. Average flexural results of corrugated PP sheets (Profile: 177/51) up to 10-year natural weathering (three-point loading, 1100 mm span)

	1 month*	8-year†	10-year‡
LOP (kN m^{-1})	/	3.3	3.0
Peak load (kN m^{-1})	7.23	7.21	6.72
Deflection at peak load (mm)	75	73	71
Sheet thickness (mm)	6.4	6.5	6.1

*6 sheets used. LOP value is not available — only peak load and deflection were recorded.
†4 sheets used.
‡8 sheets used.

the area under the load–deflection curve beyond this point was not included. Although not shown on Figs 3 and 4 the hybrid sheets are additionally able to sustain a substantial load by the polypropylene after the peak load at the breakage or pull-out of the glass fibres.

CONCLUDING REMARKS

No strength or toughness reductions have been found after exposure to natural weather as roofs on buildings for 6–10 year for corrugated hybrid and PP sheets, respectively. The hybrid sheet contained fibrillated polypropylene networks as well as alkali resistant glass fibres, and the PP sheet contained solely fibrillated polypropylene networks. The exceptional toughness of the sheets, resulting from the fibrillated polypropylene networks, is a considerable advantage for practical roofing to resist impact.

The flexural peak load of the hybrid sheets increased by about 20% after a 6-year exposure period, implying that the aging for 6 year of the hybrid sheets was not sufficient for alkali attack of the glass fibres by the cement matrix to become apparent. It is possible that the improved bond between the glass and the cement matrix was a reason for the increased load bearing capacity of the hybrid sheets. Six years of weathering is too short to draw a conclusion and longer-term weathering tests on the hybrid sheets are in process.

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