TREATMENT OF AN EXPOSED ROOFING CONCRETE SLAB WITH A COMPOSITE MEMBRANE AND A VISCOUS-PLASTIC COPOLYMERIC RESIN

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ABSTRACT:

It is the purpose of this paper to study the application of industrial wastes derived from synthesis of styrene and scraps of the composite used as internal lining in telephone cables in building construction roofing. Such scrap is presently melted for aluminium recovery so that the copolymer lining is totally destroyed. Similarly, the styrene waste which represents a disposal problem is normally incinerated causing environmental pollution. The modified polystyrene in the form of a viscous-plastic resin adheres well to the cementitious substrate sealing its pores. The aluminium composite placed on top of this resin provides additional watertightness producing a reliable waterproofing system. Laboratory and field tests confirm the effectiveness of the proposed waterproofing concept. Given the lower costs of the raw materials and of the modification procedures, it is hoped that the adoption of the new hybrid system is beneficial to its potential users and contributes to environmental control. Financial support for this study was provided by The State of São Paulo Research Foundation (FAPESP).

KEYWORDS:

Roofing, Waterproofing, Composites, Viscous-plasticity, Recycling.

INTRODUCTION

The industrial activity generates a variety of by-products in large quantities which may oftentimes represent waste materials to be disposed. This fact is even more true in the petrochemical industry where the residues may not have a consistent pattern. It may be generated in different forms resulting from various production processes. This creates a serious waste disposal problem given the great emphasis in present day environmental protection policies. In the case of the petroleum industry wastes, the disposal is often accomplished through incineration whose gaseous and toxic products may cause environmental pollution problems. There is, thus, a great need for creative disposal of the industrial wastes, recycling them to other useful purposes[1].

The industrial process for styrene involves production of a residue which does not follow a definite pattern as regards its constitution, physical state or visual aspect. This residue is at times solid or semi-solid or even in the form of a high viscosity fluid. It is possible, however, to modify the consistency of a given material mixing it with one or more types of residues to produce the desirable characteristics for roofing purposes. Similarly, one must find use for the packaging industry wastes such as plastic bottles and bags made from polyethylene and polyester which also portrays an environmental problem. A good example of recycling these materials is their transformation in continuous fibres which can be used to produce non-woven fabrics of great utility for building construction and drainage works.

The manufacture of a specially designed composite for telephone cable industry also produces wastes which are normally disposed by melting to recover the metallic part. This waste is made of a composite wherein two layers of a polyethylene-based copolymer line the two sides of a thin aluminium sheet. It is formed, in general, at the beginning or at the end of spooling process.

This paper proposes the idea of employing these waste materials together in a new technology for the protection of exposed building roofs which exploits the adherence property of the resinous material and the watertightness of the aluminium composite. The viability of this idea was tested [5] on a small plaque of concrete to which the resin-composite system was applied. In order to evaluate the waterproofing efficiency of a lap-joint, two pieces of composite were heat-welded together. The results were quite encouraging as regards weathering behaviour of the composite, watertightness of the joint and also the adherence between the composite and the base.

In comparison to the existing roofing systems using liquid-applied asphalt, asphalt-elastomers or factory-prepared asphalt-elastomeric roofing materials, and others which are susceptible to weathering particularly the UV rays [3], the proposed system offers protection as the composite has a layer of a stainless aluminium alloy. Further, the present system, in view of the viscous-plastic characteristics of the resin, avoids the rigid contact existing between the asphaltic materials and the cementitious surfaces which is prone to cracks during thermal gradients. Thus, the proposed roofing technique presents the desirable waterproofing characteristics of hydrophobicity and viscous-plasticity of the resin as well as the watertightness of the composite.

This paper presents the techniques employed in the testing of the roofing system and its materials and also the results of these tests.

Materials and Methods

As indicated above, the proposed roofing system employs mainly two materials, the resin and the composite besides some other accessory materials. The polymeric content of the resin comprises various residues of the manufacture of styrene consisting of a mixture of styrene-monomer, thermoplastic polymers, olygomers and other organic substances. In order that this material attains certain properties desirable in practical application, a mineral material containing aluminium hydroxide is also incorporated. Finally, a terpene like d-limonene is added in order to obtain the right viscosity for use in roofing. The result {[2],[4]} is a viscous-plastic, thermoplastic, hydrophobic and self-levelling material with great adherence to cementitious substrates as long as the base is completely dry and free of dust. The resin also sticks to metals and some plastics such as rigid PVC, the material of hydraulic installation pipes and accessories.

The composite has in its interior an aluminium alloy sheet of type AA1145, of average thickness of 0.19 mm and a copolymeric covering on its two sides with an average thickness of 0.054 mm, thus producing a total thickness, on the average, of 0.298 mm. A qualitative analysis of the copolymer with the aid of infrared spectroscopy permitted evaluation of its composition as poly(ethylene vinyl acetate).

Field Testing

The test slab of reinforced concrete which received the proposed roofing system was an existing roof of a corridor and had the dimensions of 4.9 m x 5.8 m. It had a series of fissures in its underside wherefrom water percolation resulted in the appearance of various calcareous forms. The application of waterproofing materials was preceded by a sweeping operation on the upper exposed surface and washing by a hydro-compressor. The larger cracks were treated by opening them slightly using a proper tool with a refractory cutting disk to a width of 7 mm and a depth of 5 mm. These grooves were later filled with a caulking mastic. All the protuberances reminiscent from the building construction, which could hurt the composite, were identified and removed.

After the curing of the mastic, the styrene resin was applied (Photo 01). About 900 g/m^2 was just sufficient to produce a homogeneous distribution of resin over the treated surface avoiding its excess which could interfere in the next step. The resin was spread manually and simultaneously made even with the help of a wooden rake. Because of the fact that the resin has self-levelling behaviour, the vertical surfaces were treated with an alternative adhesive material with thixotropic properties that ensure its adequate attachment to such surfaces. The same adhesive was used to fix the sheet in the interior of the rain water PVC ducts before the application of the composite to the slab.

The slab surfaces and the duct interiors being properly prepared, the composite strips were secured to the surface by the adhesive effect of the resin (Photo 02). In this operation, the composite strips were unrolled over the horizontal surface in a parallel fashion, overlapping them by 3 to 4 cm. The strips were later pressed by a rubber roller of about 50 cm width in order to ensure intimate contact between the substrate and the composite. This whole operation was conducted at ambient temperature of 25°C. Strips of adequate width were later applied to the vertical surfaces of the walls as baseboard skirting. The adhesion between the composite strip and the previously treated wall was ensured with the help of a hot air gun as the wall adhesive had thermoplastic properties. The welding between the strip overlaps was also accomplished by hot-pressing a PTFE (polytetrafluoroethylene) roller in the presence of hot air from the gun (Photo 03). PTFE was found to be more advantageous than polyurethane (PU) as the roller material. Although less soft than PU, PTFE does not adhere to the composite copolymeric surface when heated, in contrast to PU whose sticking behaviour made the welding operation quite difficult.

In case of a parapet instead of a wall, the composite strip was allowed to follow it to the top and the termination over the railing was made by means of a metal cap flashing. At the portions where it was not possible to conduct the above termination due to high parapets, the composite sheet extremities were reinforced by folding and fixing it firmly to the parapets employing metallic screws and plastic washers. The joints between the wall and the sheets were finally treated with the same sealant mastic as used in the sealing of the cracks.

Materials Testing Methods

In view of the fact that the proposed roofing system is rather novel in its conception, there does not exist a set of test standards appropriate for the materials employed in it. A variety of tests applied to conventional roofing systems such as those of the bituminous type or others which use membrane-like materials were reviewed. Various categories of tests were borrowed from the existing standard practices for testing of such materials recommended by the American Society for Testing and Materials (ASTM)[6]. Specifically, these practices relate to those used for testing the engineering properties of the roofing components, thermal integrity and resistance to weathering. In the following section, the proposed tests are enumerated and results from some of them reported.

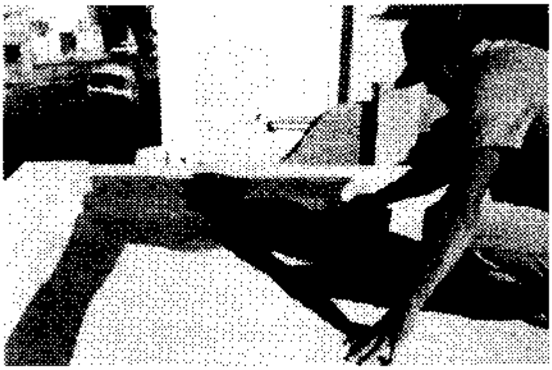

Photo 01 – Application of the resin

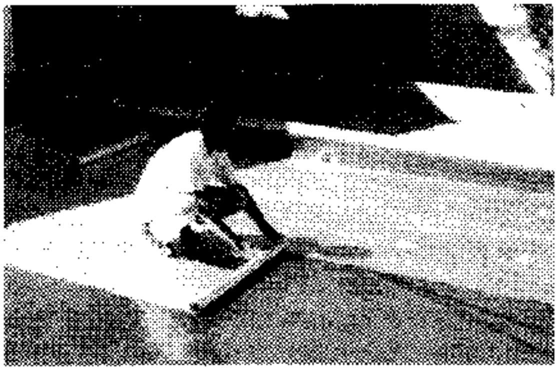

Photo 02 – Spreading the composite

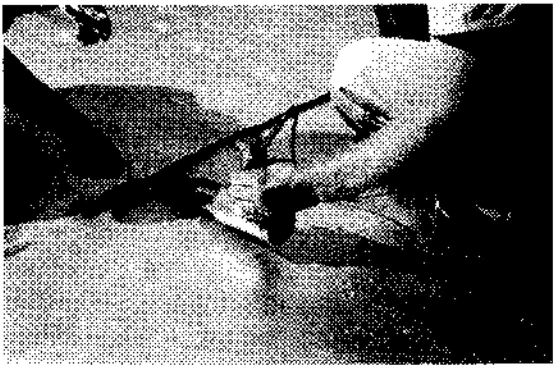

Photo 03 – Welding of the overlaps

Results

This section reports some observations on the field deployment of the roofing system and also on the materials following the relevant standard methods for testing.

Field experiments

These tests were conducted to establish some basic properties of the resin and the composite material under field conditions and propose remedial measures. Three such tests are described below:

a) A pilot test [5] was conducted to evaluate adherence of the composite sheet to the concrete base wetted with styrenic resin and the durability of the system to weathering. The results obtained in this experiment are restricted to the visual and tactile evaluations of the condition of the composite materials, of the resin and of the whole system. The set-up was accomplished in March, 1997 which, after 20 months of exposure to natural elements shows that the welded overlap used to join two pieces of composite sheet weathered well despite the deterioration of its co-polymer film due to exposure to sun light and rain. It is surmised that this deterioration occurred due to the effect of ultra-violet rays (UV). Contrarily, the same co-polymer film on the underside of the composite and also in the joint remained intact, keeping its original characteristics. The deterioration of the upper co-polymer film left the metallic laminate surface exposed to the elements. It was observed that the alloy constitution of the aluminium sheet made it resistant to corrosion which was confirmed from the continuance of the gloss of the surface. Thus, the loss of upper copolymer film of the composite due to UV effect does not imply in any way inadequate performance of the system. An investigation into the state of the resin used to glue the composite to the concrete slab showed that it did not suffer any significant alteration in its qualities and that it maintained its original adherence and viscous-plastic characteristics.

b) Another pilot test was conducted to evaluate the adequacy of some commercial paints and other materials as protection to the copolymer film against UV. The materials tested included PVA latex, water-based acrylic enamel and sheet metal lining. The material that proved to be most promising was a PVA latex because it maintains its characteristics as regards adherence to the copolymer even when it remained submerged in water for about two months. The acrylic enamel presented the worst performance loosening itself in the form of a film in five days. The lining material for sheet metal tested was also found to be unfit as a protection because of the formation of blisters and fungi when submerged. The other material tested was a recycled 500g/m^2 non-woven polyester geo-textile which provided protection not only from UV but also against mechanical injuries resulting from impacts or other actions on the surface of the composite.

c) The watertightness of the proposed system was checked on the test slab described in the previous section, following Standard Guide for Flood Testing Horizontal Waterproofing Installations (ASTM D 5957-96). Once the roofing materials were applied to the slab, it was subjected to the waterproofing test. Because of a slight inclination in the roof slab, a small part of it remained free of the water layer. No water leakage was visually observed on the underside of the slab. The moisture measurements at various points in the concrete made by a commercial moisture meter revealed values compatible with those observed in dried-in-air concrete.

Laboratory Testing

Further tests were conducted in the laboratory on the materials involved in the proposed roofing system which are described below:

a) Membrane resistance tests. The load-strain property of the composite material was tested according to ASTM Standard D 2523-78. The samples were obtained from the composite sheet in the machine direction (MD) as well as in the cross machine direction (XMD), three test specimens for each direction. The elongation of the dumbbell specimens was measured at 25°C between the reference marks and the strain expressed as percentage. The average MD strain at rupture of the composite specimens was about 10% at the average load of 12,0 kN/m, while the average XMD strain at rupture was 17% at the average load of 13,0 kN/m.

b) Tearing resistance tests. This test was used to measure the relative tearing resistance of the composite sheet in the laboratory as per ASTM Standard D 5601-94. The displacement was observed as the crosshead moved as a function of the load applied at 25°C, the test being discontinued after 2 min. The tear was a linear extension of the line of the initial cut. The average MD tear resistance for the last 1 in. of the tear in four tests was found to be 11.4 N whereas the XMD tear resistance was 16.5 N.

c) Impact resistance tests. The resistance of the proposed roofing system to impact loads was conducted as recommended by ASTM Standard D 3746–85. The test table slab was constructed in concrete and covered with the roofing materials without a joint according to the specified dimensions of 12 x 12 in. The test was conducted at 65% humidity and 25°C. The four impacts (Photo 04) caused only dents in the composite sheet and no cracks or splits were found (Photo 05), so one can conclude that the average impact damage for this test is rated as "2".

d) Puncture resistance tests. The ability of a membrane roofing system to resist static puncture loads represents an important aspect of its performance. The maximum static puncture load that the roofing samples can withstand without allowing the passage of water was tested according to ASTM Standard D 5602-94. Four test specimens were tested at 27°C and 70% humidity. The substrate used for the tests was an expanded polystyrene board though, in practice, the composite sheet is applied directly over the concrete or mortar of the slab. The static puncture resistance, that is, the load which the specimens could support for 24 hours without allowing the passage of water, was found to be 140 N. After visual inspection (Photo 06), watertightness was examined by employing a 500 mm height water column sealed to the top of the composite specimens, applied for 15 min. to the surface of the specimen that was subjected to the ball-bearing force.

e) Single-Lap-Joint adherence tests. In the proposed system, the adhesion between the overlapped strips of composite sheets is obtained by hot-welding their copolymer films in the overlap area. Although the ASTM Standard D 1002-94 purports to test the metal sheet overlaps bonded through adhesives, its procedures are equally applicable to the present case. As described in the previous section, the 10mm lap-joint for the present test was prepared by the application of manual pressure with the help of a PTFE roller while applying a hot-air jet simultaneously to the overlap. Five test specimens of 1 in. width cut from a test panel prepared according to the recommendations of D 1002-94 were subjected to shear loads 24 hours after welding operation. In all the shear tests, the joints resisted rupture, the failure being observed in the aluminium sheet, away from the joint at an average load of 327,50N/2,54 cm. This observed failing load corresponds to the property of the composite sheet previously reported in the first test above and not to that of the joint.

Further Single-Lap-Joint adherence tests were conducted to evaluate the influence of accelerated weathering and extended immersion in water over the mechanical properties of the joint. In all cases, not one specimen suffered rupture at the joint due to shearing stress, the rupture being observed only in the aluminium sheet due to tensile stress away from the joint. It is important to note that, in the case of these two batteries of tests, the rupture loads were inferior than the average of 327,50 N/in. observed above probably because of the deterioration of copolymer films (due to accelerated weathering), or any interaction of the films with water. To evaluate the influence of thermal fatigue over the joint properties, a series of tests were conducted following the same procedures, after submitting the specimens to several temperature cycles, in which the specimen temperature was increased up to 65°C and immediately decreased to about 25°C, with the purpose of simulating thermal gradients in the field, when rain falls on the roofing material after a long exposure to sun in a summer day. As observed in the other Single-Lap-Joint Adherence tests, not one specimen suffered rupture due to shearing stress, the rupture being observed in the aluminium sheet, away from the joint, due to tensile stress. The average load for rupture was always superior than 305 N/2,54 cm, but one could observe appreciable decrease in tensile strain for all specimens (below 10%), probably due to some kind of stiffening of the alloy material caused by the cyclic action of thermal gradients.

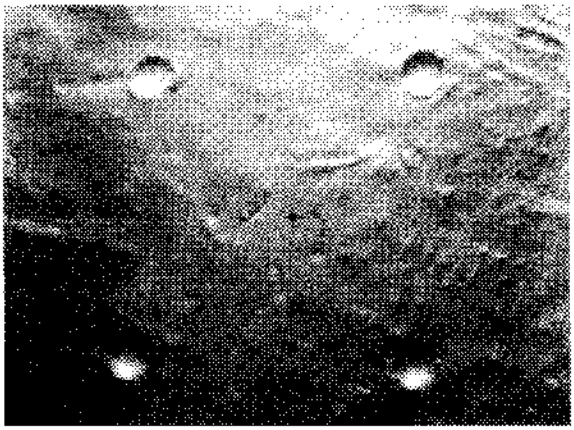

Photo 04 – Impact test

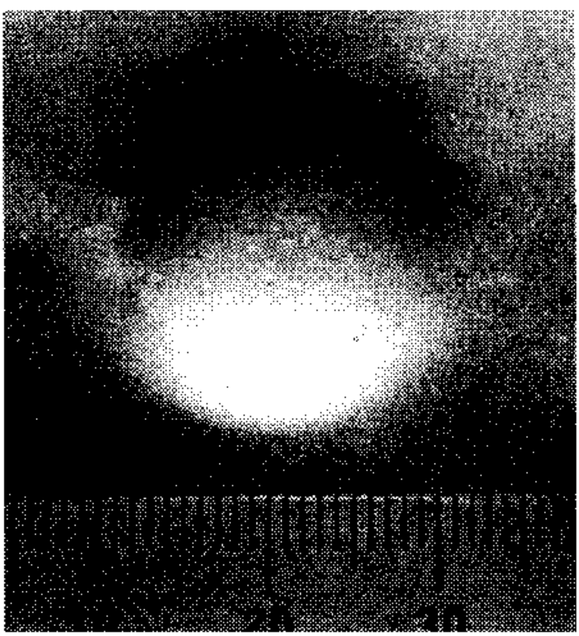

Photo 05 – Detail of the dent in impact test

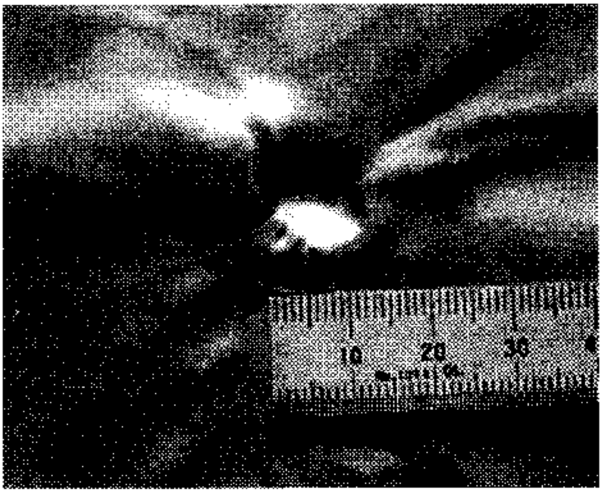

Photo 06 – A view of the composite in puncture test

f) Corrosion tests. These tests were conducted to evaluate whether and how the composite would behave upon the incidence of an alkaline solution with pH = 14. A simple way to grant mechanical protection to waterproofed surfaces is to apply cement plasters over them to prevent puncture, impact, abrasion among other injuries. However, the presence of rain water in the plaster porous matrix induces the development of an alkaline solution which can corrode the membrane if it has a metallic component such as aluminium[7]. The tests were then aimed at applying the alkaline solution over a piece of composite sheet and to measure the electrical potential existing between the composite and the solution, so as to evaluate whether the copolymer present in the surface of the composite would be effective to prevent alkaline attack on the metallic alloy inside. The potential was measured to be zero for a period of almost 180 days, but after this period, potential fell reaching -1,1 V. This oxidation potential for aluminium shows that the polymeric film was not able to withstand alkaline percolation anymore. This result implies the impossibility for using common cementitious surfacing to the developed system, even though some polymeric mortars in the form of thin coating layers could be used once the polymer encircles the cement grains preventing it from spreading its alkaline material to water.

g) Tests for identifying the chemical composition of the resin. Infrared Spectrometry (FT-IR) showed that the polymeric portion of the resin is basically polystyrene; X-ray Diffractometry disclosed the main mineral additive that was found to be Aluminium Hydroxide.

h) Rheology of the resin. These tests showed that the resin is fundamentally a Newtonian fluid in a range of temperatures between 25°C and 35°C, in which the resin application is done. This result shows that no difficulty should arise in the field practice due to resin rheology.

Conclusions

The present study was aimed at evaluating the applicability of a hybrid resin-composite roofing system employing some waste materials. Various field and laboratory tests were conducted to establish the engineering properties of the components of this system and its resistance to weathering. The field experiments showed that the composite sheet maintained its adherence to the substrate and also the welded overlap joints weathered quite well during 20 months of exposure to natural elements. It was found that the performance of the copolymer film of the composite material exposed to UV rays of the solar radiation could be significantly improved by painting it with a PVA latex or protecting it by spreading a recycled non-woven polyester fabric. Further, these tests showed that the system with overlapped joints and other junctions was leak-proof with no sign of moisture on the underside of the roofs waterproofed with the proposed system.

The laboratory tests on mechanical properties of the materials included resistance of the composite to strain, tearing, impact and puncturing. The results show that the composite material has adequate properties to be used in roofing practice. Further, the tests of the apparent shear strength of the single-lap-joint as proposed here showed that it is stronger than the composite material itself, even after submitted to weathering, thermal fatigue and extended immersion in water.

From the observations made on the proposed resin-composite hybrid roofing system during these tests, one concludes that it is a suitable and viable system which is promising from various points of view. It is simple to apply, uses cheaper materials and is durable because of the presence of a layer of stainless light metal besides its positive environmental implications as it proposes recycling the industrial wastes. These conclusions are also based on the current use of this roofing system on medium-size buildings and small residential structures. The system is specially suited to the Brazilian market because of a gap existing in the appropriate roofing alternatives for low-income housing. One observes in Brazil that there is a growing practice of making hybrid slab roofs constituted of reinforced concrete and hollow ceramic bricks which are quite susceptible to leakage. The proposed system harmonizes well with this kind of slab to provide an economical solution for roofing.

The use of the system requires some precautions as regards cleaning and drying the substrate, application of the resin and appropriate welding operation. Special care is necessary during the application of the resin as there is a tendency towards the formation of bubbles of air trapped in the interstices of the substrate surface. This can be remedied by waiting for the bubbles to burst before laying the composite sheets on it.

The use of simple cementitious plasters as mechanical protection to this roofing system is not recommended, as it could be hazardous, in the long-term, to membrane watertightness, though polymeric mortars have been used successfully.

Acknowledgements

The authors are grateful to The State of São Paulo Research Foundation for the research support provided under Contract number 97/07221-8. The authors also wish to thank the advice of Prof. Elias Hage Junior and the DEMa – Department of Materials Engineering of the Federal University of São Carlos for their support in the laboratory tests.

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