

Adhesion study of vinylchloride–vinylacetate–maleic acid terpolymer/butylated melamine–formaldehyde resin blends

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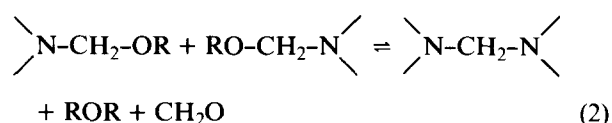
Vinylchloride–vinylacetate–maleic acid terpolymer (VMT) and butylated melamine–formaldehyde resin (BMF) were blended in different weight fractions as 10% (weight by volume) solutions in cyclohexanone. Compatibility of the blend was studied by the mutual solvent method and morphology by polarized microscopy. The dependence of curing temperature and curing efficiency on weight fractions of VMT and BMF was studied. The blend solution was applied as a surface coating for aluminium and mild steel (untreated and acetone washed). Adhesion of the stoved coatings was determined using the pressure-sensitive tape snatch test before and after immersion in water for 168 h. Adhesion was further studied in the dry state by a scratch test on untreated mild steel and by a peel test after heat sealing and curing coated untreated aluminium. Failure surfaces generated by the peel test were examined using scanning electron microscopy. The participation of the different functional groups present in the VMT and BMF in bonding with aluminium was established by Fourier transform infra-red spectroscopy. The coating was further characterized by bend, salt water immersion and natural weathering tests.

Key words: adhesion; coatings; solution blending; blend compatibility; curing; mechanical properties; environmental testing

Vinylchloride–vinylacetate–maleic acid terpolymer (VMT) has been blended with butylated melamine–formaldehyde resin (BMF) in different weight fractions as 10% weight by volume (w/v) solutions in cyclohexanone. The present paper reports the compatibility of the VMT/BMF blends as revealed by the mutual solvent method and by examination of the phase morphology using a polarizing microscope. In the mutual solvent method, freshly prepared blend solutions are kept under static conditions to study the layer separation of the blend solutions¹: compatibility is said to prevail if phase separation does not occur: if phase separation does occur the two polymers are said to be incompatible with one another. The polarizing microscope is a useful instrument to determine whether

a blend is in a single phase (compatible) or in multiphase (incompatible)^{2,3}.

For a coating composition comprising a polymer (PH) having an active hydrogen group (such as –OH, –CONH₂ or –CO₂H) and amino resin, two main reactions occur when the composition is heated and a crosslinked structure is obtained^{4–6}:



Reaction (1) is termed co-condensation and reaction (2) is termed self-condensation. It is assumed that some of the $-CO_2H$ groups present in VMT are utilized for curing the BMF resin. The dependence of the curing temperature on the weight fractions has been investigated by heating the cast films at different temperatures for a fixed time, and the extent of curing measured by immersing the cured blends for 72 h in cyclohexanone at room temperature^{5,6}. It is known that resin containing vinylchloride and vinylacetate suffers thermal degradation⁷. Before studying the curing characteristics of VMT/BMF blends, degradation of VMT films (kept under curing conditions) was analysed from UV-visible spectra in tetrahydrofuran (THF) solution to find the operating temperature limit.

The free carboxylic groups in VMT are highly polar and therefore have a strong affinity for metal surfaces through hydrogen bonding^{2,8}. Furthermore, at high temperatures, other polar groups such as chlorine and ester present in VMT may orient in such a way that they come into sufficiently close contact with active centres present on the metal surface for the secondary valencies to come into operation and lead to metal-to-VMT adhesion. The ether group (C-O-C) present in the cured BMF is moderately polar⁹ and may be active in metal-to-BMF adhesion, thereby giving moderate adhesion on metal surfaces¹⁰.

The present paper also deals with coating of the VMT/BMF blends on untreated and acetone-washed aluminium and mild steel surfaces. After stoving the coatings at the appropriate temperature and time, the dependence of coating properties (such as adhesion, and resistance to bending, salt water immersion and natural weathering) on composition of the blends was determined.

Experimental details

VMT supplied by Union Carbide International Company, USA, and BMF from Himalaya Resins and Paints Pvt Ltd, India, (% free formalin, max 2; acid value, 1.7; solid content, 61% by weight in butylalcohol) were used. Al foil from India Foils Ltd, India, of thickness 0.05 mm and purity 99.2%, and mild steel from Bokaro Steel Plant, India, grade 18 SWG, were used in this work.

VMT and BMF were blended in 20, 15 and 10% cyclohexanone solutions (w/v). An appropriate amount of butylalcohol was added to each blend to maintain a constant alcohol content in the blends. Thin films of VMT/BMF blends were cast from the same solutions on glass and mercury surfaces in a dust-free chamber at room temperature. After evaporation of the solvents the films were dried under vacuum at 40°C for 7 days and used for blend characterization and blend curing studies. The average film thickness of the blend cast on glass was 23 μm and that for the blend cast on mercury was 40 μm .

Layer separation of the blend solutions was studied after keeping each solution under static conditions for 48 h (Reference 1).

A Leitz orthoplanar polarizing microscope utilizing plane polarized light was used for studying the morphology of the blends^{2,3}.

To determine the degradation of VMT resin, samples

were heated to temperatures of 100–160°C at 10°C intervals, for 15 min in each case, and the UV-visible spectrum in 10% (w/v) THF solution was examined for each sample. Spectra were obtained on a Hitachi U3200 spectrophotometer.

Films cast from the respective blend solutions were heated at temperatures of 100–160°C at 10°C intervals, for 15 min in each case, until degradation of the VMT commenced. After curing the films, the extent of curing was measured by immersing the cured blends for 72 h in cyclohexanone at room temperature. The films were dried under vacuum until constant weights were reached^{7,8}. Thus the temperature at which optimum cure took place and curing efficiency at the optimum cure temperature were determined.

VMT/BMF blends were made by blending 10% (w/v) solutions of each resin in cyclohexanone; these were then plasticized with 5% (by weight of total resin) of dibutyl phthalate prior to coating. Methods of blending and coating, techniques of measuring critical surface tensions of untreated and acetone-washed metal surfaces and the specification of panels are given elsewhere^{2,11,12}. The coated panels were stoved at appropriate temperatures for 15 min before characterization. The average coating weight was 1.2 g m⁻². Average critical surface tensions of untreated Al and mild steel were 32 and 42 mN m⁻¹, while those of acetone-washed surfaces were 38 and 57 mN m⁻¹ respectively.

Adhesion of the coating on untreated and acetone-washed metal surfaces was assessed by a pressure-sensitive tape (PST) snatch test in the dry state and after immersion in water. In the dry state PST was pressed uniformly over the coated surface and then snatched off. For satisfactory adhesion the test coating should not transfer onto the PST¹²⁻¹⁴. The coated panels were then immersed in distilled water for 168 h. After the panels had been removed from the water and the surface moisture wiped off by gentle rubbing with paper towels, a piece of PST was immediately pressed uniformly over the coated surface and then snatched off.

Adhesion of the coating on untreated mild steel was studied by a scratch test^{12,15,16} in the dry state. In this method, a needle, equipped with a plate on to which weights are loaded, is placed on the coated panel (locked on a holder) and moved across the panel under test for approximately 60 mm at a particular velocity. The angle between the needle and the panel is also maintained at a particular value. Weights are added gradually and after each needle movement the panel is examined for a scratch, the minimum weight required to produce a scratch being recorded. The higher the weight required to scratch the coated panel, the greater is the adhesion between the panel and the film former. An Erichsen¹⁵ electrical scratch tester was also used for testing the adhesion by scratch.

For measuring peel strength^{2,17}, two coated Al panels, 25.4 mm in width, were bonded together at 200°C under 500 kg m⁻² pressure and 5 min dwell time using a Moore hydraulic press. Prior to bonding, the VMT/BMF blend coated panels were vacuum dried for 7 days at 40°C to remove the solvent. The bonded Al panels were separated at a rate of 50.8 mm min⁻¹ in a Scott tensile testing machine². Failure surfaces generated by the peel test^{12,18} were examined by

scanning electron microscopy (SEM) in a Philips PSEM 500 instrument.

The interaction between the polar groups present in VMT and BMF with the aluminium surface was studied by Fourier transform infra-red (FTIR) spectroscopy, using a Perkin-Elmer 1600 series FTIR instrument under the attenuated total reflectance (ATR) mode^{18, 19}.

Metal surfaces are very often found to be oily or greasy, despite annealing or other precautionary measures, due to the presence of residual lubricants previously applied during the metal rolling operation²⁰. Therefore the purpose of the acetone wash was to degrease the metal surfaces²¹. Cleaning of the metal surfaces was carried out by rinsing with acetone and subsequent drying in a stream of warm air.

Bend testing was carried out using a mandrel of diameter 6.35 mm. This test as performed and reported² may be regarded as indicating a balance between flexibility, extensibility and adhesion of the coating, no crack development in the coating on the outer side of the bent strip indicating a good balance of the said properties. The test specimen was bent through 180°C in 1 s.

The salt water immersion test (3.5% NaCl solution, at 30°C) was carried out for 168 h, and photographs were used to examine degree of corrosion^{2, 22}.

Weathering in the prevalent industrial environment in Calcutta was carried out on the panels (holding the panels facing south at an angle of 45°) for 720 h. Changes in the surface morphology of the weathered coatings were examined using SEM (Philips PSEM 500), for both Al and mild steel panels^{2, 22}.

Results and discussion

The study of layer separation of the blend solutions by the mutual solvent method showed that the VMT/BMF blends are compatible as 10% (w/v) cyclohexanone solutions at all weight fractions (Table 1). No layer separation took place, indicating the presence of one phase only.

The compatibility of VMT/BMF blends cast from 10% (w/v) cyclohexanone solutions also finds support from

optical micrographs of the blends (Fig. 1). The phase morphology of the 83:17, 62:38, 36:64 and 16:84 VMT/BMF blends (Figs 1(a), (b), (c) and (d) respectively) indicate that they are practically compatible when cast from 10% (w/v) cyclohexanone solution. Thus VMT/BMF blends are made in 10% (w/v) cyclohexanone solution, plasticized with 5% (by weight of total resin) dibutyl phthalate and coated on untreated and acetone-washed Al and mild steel panels.

Analysis of the UV-visible spectra of VMT films in THF solution shows that heating at 140°C for 15 min resulted in degradation of the VMT, as indicated by the high absorption in the 250–350 nm region and the shoulder around 275–300 nm (Fig. 2(c)) due to the presence of conjugated double bonds²³ produced by the elimination of HCl and/or acetic acid⁶ from VMT. Such absorptions were very low and the shoulder was absent in UV-visible spectra obtained from VMT solutions before heating (Fig. 2(a)) and after heating at 130°C for 15 min (Fig. 2(b)). It may be concluded that the samples containing VMT may be heated for curing within 15 min at 130°C.

The blend films cast from 10% (w/v) cyclohexanone solution, after vacuum drying, were heated at 100, 110, 120 and 130°C for a residence time of 15 min in each case (except for pure BMF) and the films immersed in cyclohexanone for 72 h. From the study of cyclohexanone-soluble materials, Fig. 3, it was found

Table 1. Compatibility study of VMT/BMF blends (10% (w/v) solutions in cyclohexanone) by mutual solvent method

Blend weight fraction		Layer separation of blend solution after 48 h
VMT	BMF	
0.83	0.17	No layer separation
0.62	0.38	"
0.36	0.64	"
0.16	0.84	"

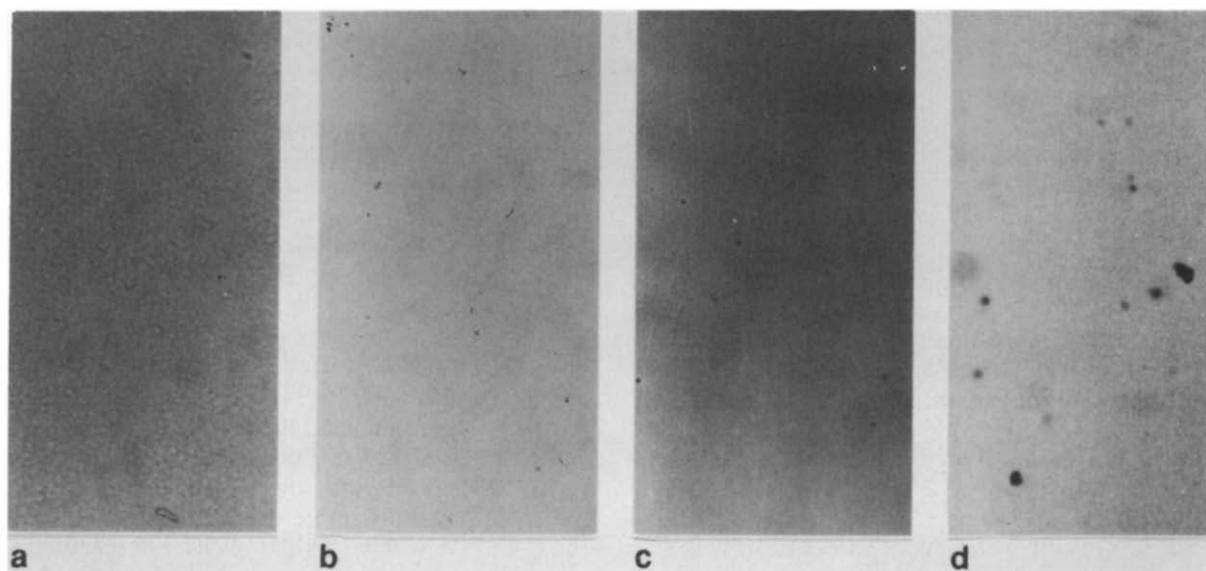


Fig. 1 Phase morphology of (a) 83:17, (b) 62:38, (c) 36:64 and (d) 16:84 VMT/BMF blends cast from 10% (w/v) cyclohexanone solution (magnification $\times 400$)

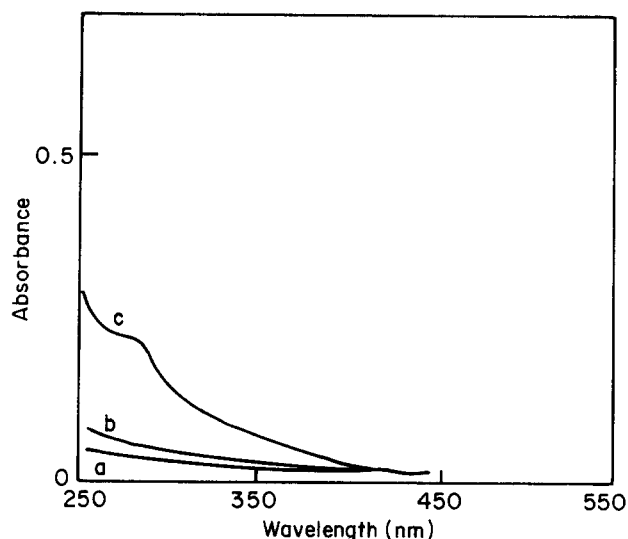


Fig. 2 UV-visible spectra (10% THF solutions) in 250-550 nm region for (a) VMT, (b) VMT heated at 130°C for 15 min and (c) VMT heated at 140°C for 15 min

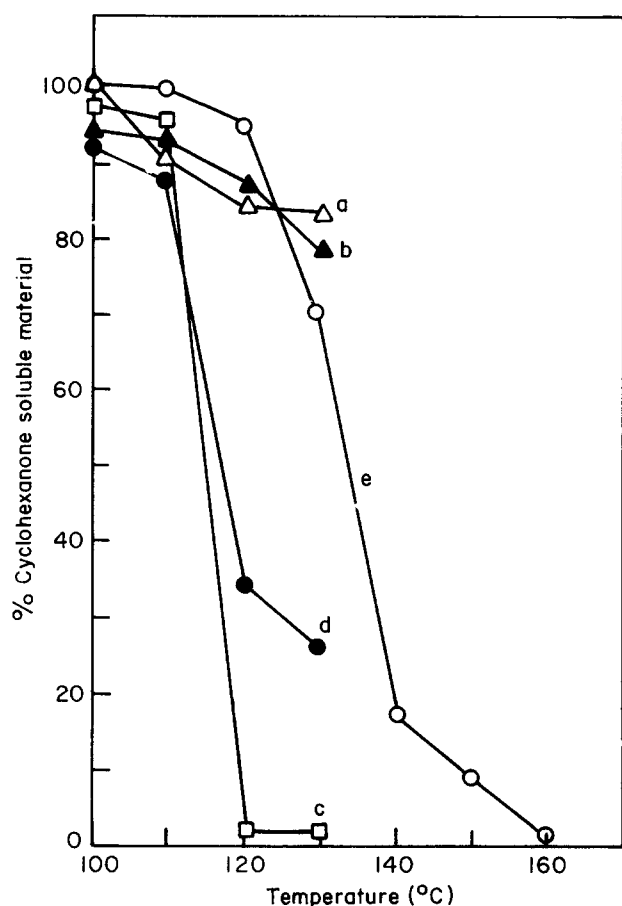
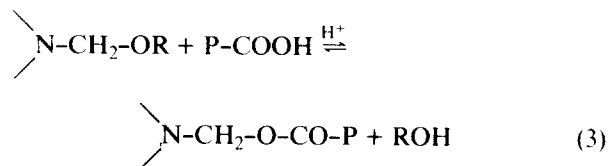


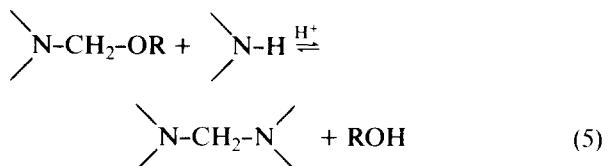
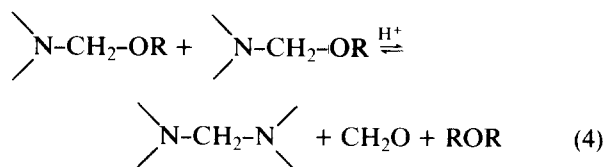
Fig. 3 Curing efficiency of VMT/BMF blends studied by % cyclohexanone-soluble materials. (a), (b), (c), (d) 83:17, 62:38, 36:64, 16:84 blends, respectively, (e) pure BMF

that the optimum curing temperatures of the VMT/BMF blends were 130°C for the 83:17, 62:38 and 16:84 ratios, 120°C for the 36:64 ratio and 160°C for pure BMF. It is also clear from the above study that curing efficiency of the VMT/BMF blend decreases in the order 36:64 (Fig. 3(c)) > 16:84 (Fig. 3(d)) > 62:38 (Fig. 3(b)) > 83:17 (Fig. 3(a)).

The possible reaction between BMF and VMT (P-COOH) is⁴:



and the possible reactions between BMF molecules are⁴:



where R = H or C₄H₉.

From the study of % cyclohexanone-soluble material it may be concluded that the co-condensation reaction (3) took place between VMT and BMF, particularly at VMT/BMF ratios of 36:64 and 16:84. This study again confirms that the stoving condition for the pure VMT/BMF blend is 130°C for 15 min and that of the pure BMF is 160°C for 15 min. Thus VMT/BMF blends coated on metal surfaces were stoved (in an air oven) at 130 ± 2°C for 15 min and pure BMF coatings were stoved at 160 ± 2°C for 15 min before characterization of coating properties.

Adhesion of cured VMT/BMF coatings to untreated and acetone-washed Al and mild steel was studied by the PST snatch test before and after immersion in water for 168 h. The test revealed that coatings on untreated Al remained unchanged after immersion in water, with no transfer of coatings to the tape except in the case of the coating with 100 wt% of BMF. In the latter case about 30-40% of the coating was transferred to tape, both before and after immersion in water. On acetone-washed Al, adhesion of VMT/BMF coatings was the same before and after immersion in water with no transfer of coatings to the tape. Similarly, for untreated and acetone-washed mild steel, the PST snatch test again revealed that no coating was transferred to the tape in the dry state. However, adhesion after the water immersion was not satisfactory. For coatings containing ≥62 wt% VMT, 15-25% of the coating was removed; for coatings with ≤84 wt% BMF, 40-55% of the coating was removed; and for the coating with 100 wt% BMF about 70% of the coating was removed, irrespective of the surface treatment.

The free carboxylic groups in VMT react with BMF to give a crosslinked structure⁴⁻⁶, thus reducing the number of free carboxylic groups available for interaction with the metal during adhesive bonding. But the overall adhesion (in the dry condition) of the VMT/BMF blend coatings on Al and mild steel is satisfactory as revealed by the PST snatch test. This may be explained as follows:

- the ether group (C-O-C) present in the cured BMF is moderately polar and may be active in metal-to-BMF adhesion; and
- other polar groups such as chlorine and ester present in VMT may interact with the metal to produce metal-to-VMT adhesion.

A shift in the IR spectrum (Fig. 4) for the aliphatic ether (C-O-C) group²⁴ was observed from around 1094 cm^{-1} (Fig. 4(a)) for pure BMF to around 1087 cm^{-1} (Fig. 4(b)) for the BMF-coated untreated Al panel stoved at $160 \pm 2^\circ\text{C}$ for 15 min. This shift may be due to orientation of ether groups in such a way that they come into sufficiently close contact with active centres present on the metal surface and secondary valence bonds come into operation.

Shifts in the IR spectrum were also observed for the isotactic chlorine²⁵ and syndiotactic chlorine²⁵ groups: from around 690 and 612 cm^{-1} , respectively, for pure VMT (Fig. 5(a)) to around 688 and 609 cm^{-1} , respectively, for the VMT-coated untreated Al panel stoved at $130 \pm 2^\circ\text{C}$ for 15 min (Fig. 5(b)). In addition, the band around 1734 cm^{-1} for the ester group of pure VMT shifted to around 1736 cm^{-1} and that for the free

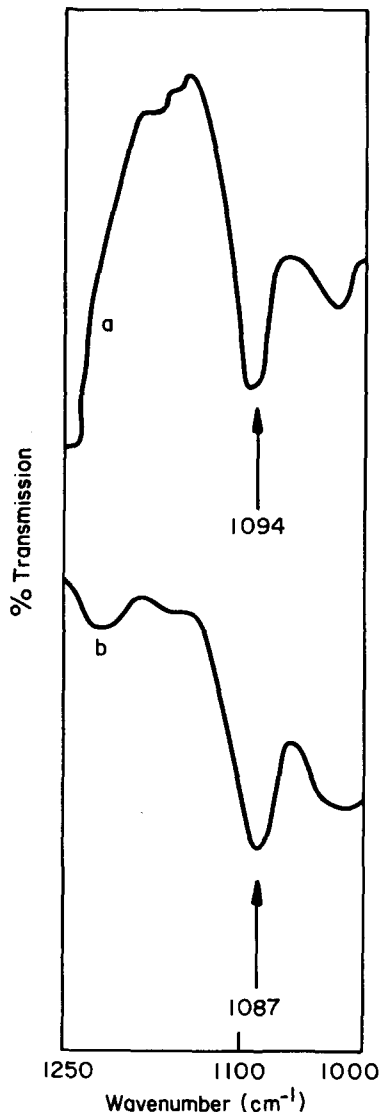


Fig. 4 FTIR spectra, under ATR mode, in the $1250\text{--}1000\text{ cm}^{-1}$ region for (a) pure BMF and (b) BMF-coated untreated aluminium panel, stoved at $160 \pm 2^\circ\text{C}$ for 15 min

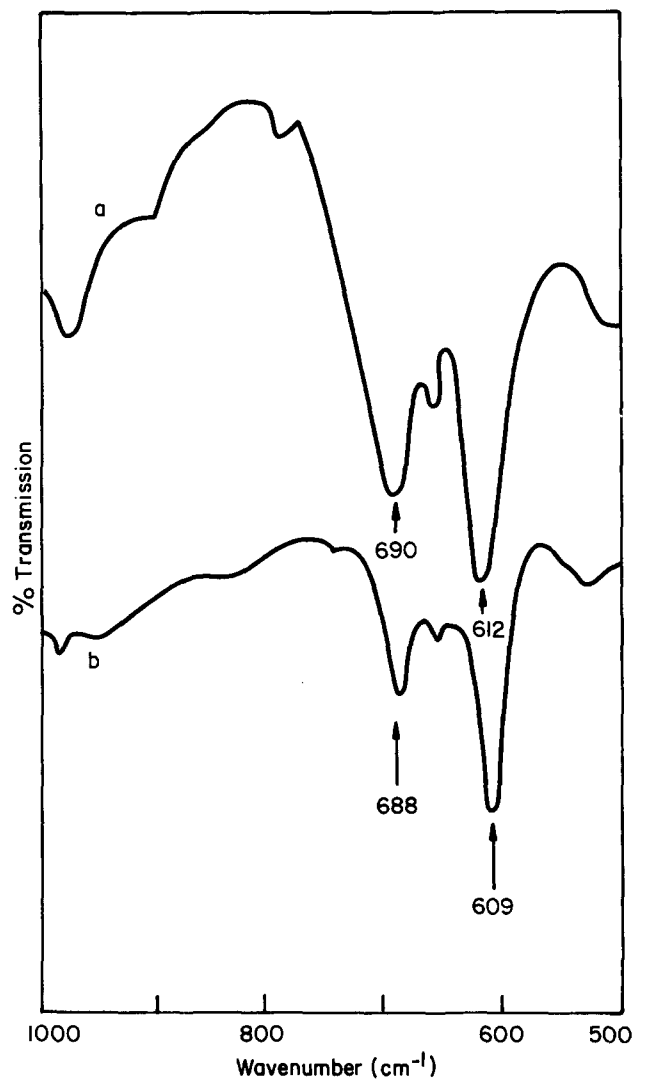


Fig. 5 FTIR spectra, under ATR mode, in the $1000\text{--}500\text{ cm}^{-1}$ region for (a) pure VMT and (b) VMT-coated untreated aluminium panel, stoved at $130 \pm 2^\circ\text{C}$ for 15 min

carbonyl (carboxylic) group, around 1718 cm^{-1} for pure VMT, shifted to around 1707 cm^{-1} . Thus the absorption of the free carboxylic group is shifted significantly upon adhesion of pure VMT to metal; however, since these groups may react with BMF during cure, their contribution towards adhesion of cured VMT/BMF blends on untreated Al will be insignificant. Therefore adhesion in this system is provided by the chlorine and ester groups of VMT and the ether group of BMF and, by analogy, the same results are also expected for other metal surfaces. The shift of bands observed for chlorine and ester groups is due to orientation of these groups in such a way that they come into sufficiently close contact with active centres present on the metal surface for the secondary valence bonds to come into operation.

The adhesive bond in any liquid environment is mainly affected by the three following factors^{12, 26, 27}:

- the diffusion of liquid molecules through the coating film to the polymer/metal interface;
- the chemical action between the diffused molecules and the metal, the coating or both; and
- debonding or separation of organic coatings by the liquid.

It is considered that debonding of a coating by water is initiated by the direct interaction of water molecules with adhesive bonds at the metal/coating interface²⁷. It is likely that debonded areas exist at this interface where water molecules may accumulate and that the water volumes grow laterally along the interface, lateral debonding occurring when the stress due to water exceeds the adhesive bond strength. This lateral growth of the water layer is prevented by strong adhesive bonds^{12, 27}. For two coatings with different water diffusion rates, the accumulation of water at the metal/coating interface will be lower for the coating with the lower water diffusion rate for a fixed time period¹². The diffusion or permeability of water through amino resin (BMF) is high compared with that through vinylchloride-based polymers (VMT)²⁸. The chemical action of water on both VMT and BMF is low²⁹, whereas the degree of corrosion of mild steel by water is higher than that of Al^{30, 31}.

The 6 cm⁻¹ shift in the ether band from the value for pure BMF indicates that interaction (adhesive bonding) takes place between the metal and BMF. The effect of this interaction is clearly not high enough to ensure satisfactory adhesion of BMF on oily (untreated) Al surfaces either before or after immersion in water (the PST snatch test resulting in coating being transferred to the tape), but does satisfy the condition required for satisfactory adhesion on acetone-washed Al both before and after water immersion.

The cumulative effect of interactions between the polymers present in a particular blend system and a metal surface is the sum of the interactions of specific groups (such as chlorine and ester of VMT and ether of BMF). The satisfactory adhesion of VMT/BMF blends on untreated and acetone-washed Al before and after immersion in water can therefore be attributed to the following:

- 1) the cumulative effect of interactions between the polymers and the metal generated by chlorine, ester and ether groups is high enough to give strong adhesive bonds;
- 2) the low-to-moderate rate of diffusion of water through the coatings; and
- 3) the low degree of corrosion of Al by water.

It is clear from the PST snatch test results that the cumulative effect of the chlorine, ester and/or ether interactions satisfies the condition required for satisfactory adhesion of pure VMT, VMT/BMF blends and pure BMF to untreated and acetone-washed mild steel

in the dry state. However, in the cases of mild steel panels coated with VMT/BMF blends after water immersion, adhesion of coatings containing ≥62 wt% VMT is fair, for coatings containing ≤84 wt% BMF adhesion is poor and for coatings containing 100 wt% BMF adhesion is very poor, irrespective of the surface treatment. This is due to the higher diffusion rate of water through coatings with a higher concentration of BMF, and the higher degree of corrosion of mild steel by water. Again the cumulative effect of the interactions between the polymers and mild steel at higher concentrations of BMF may not be high enough to resist the lateral debonding of the coatings by water²⁷.

The adhesion of VMT/BMF blend coatings on untreated mild steel as assessed by the scratch test is reported in Table 2. It is clear that the adhesion of the blend increases with increasing VMT concentration of the blend. These observations are attributed to the higher degree of coating-metal interaction at higher concentrations of VMT in the blend.

The peel strength of a convertible coating depends on:

- the force of adhesion between the metal surface and the fused coated layer; and
- the intramolecular cohesive force of the fused coated layer itself, which in turn depends on the degree of crosslinking in the fused coating. The higher the degree of crosslinked structure, the greater will be the cohesive force within the fused coating³².

The mode of failure during peeling of a convertible coating with a highly crosslinked structure will probably be through adhesive failure, i.e., failure between the metal surface and coated film. Convertible coatings with highly crosslinked networks may undergo cohesive failure during peeling provided the force of adhesion between the metal surface and the fused layer is sufficiently high.

Results of peel strength are given in Table 2. It can be seen that as the VMT concentration of the blend increases, adhesion of the blend on untreated Al increases. This observation is attributed to the greater interaction between the coating and the metal at higher concentrations of VMT in the blend.

SEM micrographs of peel surfaces from untreated Al/Al joints bonded with VMT/BMF blends and pure BMF are shown in Fig. 6. Failure of the joint bonded with the 62:38 VMT/BMF blend was cohesive (Fig. 6(a)), whereas the adhesive failure mode was observed for

Table 2. Results of testing cured VMT/BMF blends cast from 10% (w/v) cyclohexanone solutions

Blend weight fraction		Adhesion of the coating on untreated mild steel by scratch (kg)	Peel strength on untreated Al (kg m ⁻¹)
VMT	BMF		
1.00	0.00	1.5*	20.3*
0.83	0.17	1.3	16.0
0.62	0.38	1.2	14.3
0.36	0.64	1.1	12.5
0.16	0.84	0.8	11.0
0.00	1.00	0.6	7.0

*Source — References 2 and 12



Fig. 6 Scanning electron micrographs of peel surfaces of Al joints bonded with: (a) 62:38 blend, $\times 600$; (b) 36:64 blend, $\times 1200$; (c) pure BMF, $\times 150$

joints bonded with the 36:64 VMT/BMF blend (Fig. 6(b)) and with pure BMF (Fig. 6(c)). For the 62:38 VMT/BMF blend, the study of curing efficiency (Fig. 3) showed that the system has lightly crosslinked structure, so that cohesive failure in the peel test is to be expected. In addition, the high degree of interaction between the coating and metal results in high peel strength and thus cohesive failure. However, the 36:64 VMT/BMF blend and pure BMF have highly crosslinked structures, so that adhesive failure took place. The nature of the rupture on the surfaces of joints bonded with pure BMF (Fig. 6(c)) indicates the poor peel strength of the coating film, there being a continuous tear-off portion of BMF coating from the metal surface.

All the coatings on untreated and acetone-washed Al and mild steel showed no signs of cracks on the bent edge during bend testing, thus the coatings have a balance between flexibility, extensibility and adhesion.

Results of salt water immersion tests are shown in Fig. 7. It is clear from the photographs that the corrosion resistance of the coatings on Al and mild steel decreases in the order 83:17 > 62:38 > 36:64 > 16:84 VMT/BMF blends > pure BMF.

Surface morphology of the weathered coating samples was examined by SEM; the results are shown

in Fig. 8. The presence of cracks and/or pin-holes on the weathered coating indicates poor durability. The durability of coatings on Al and mild steel follows the order 36:64 > 83:17 > 62:38 > 16:84 VMT/BMF blends > pure BMF. Curing efficiency follows the order pure BMF > 36:64 > 16:84 > 62:38 > 83:17 blends (Fig. 3). The VMT concentration in the specimens decreases in the following order 83:17 > 62:38 > 36:64 > 16:84 blends > pure BMF. Judging from the surface morphology, it may be concluded that durability depends on both curing efficiency and VMT concentration. That the durability of the 36:64 VMT/BMF blend is better than that of the other blends may be attributed to its higher crosslinked structure and optimum VMT content.

Conclusions

From the study of adhesion by PST snatch, scratch and peel tests, it may be concluded that as the amount of VMT in the VMT/BMF blends increases the adhesion of the blends on metal surfaces improves. Adhesion of the coatings after immersion for 168 h in distilled water is not affected by the presence of oil on the metal surface. The diffusion of water through the coating film,

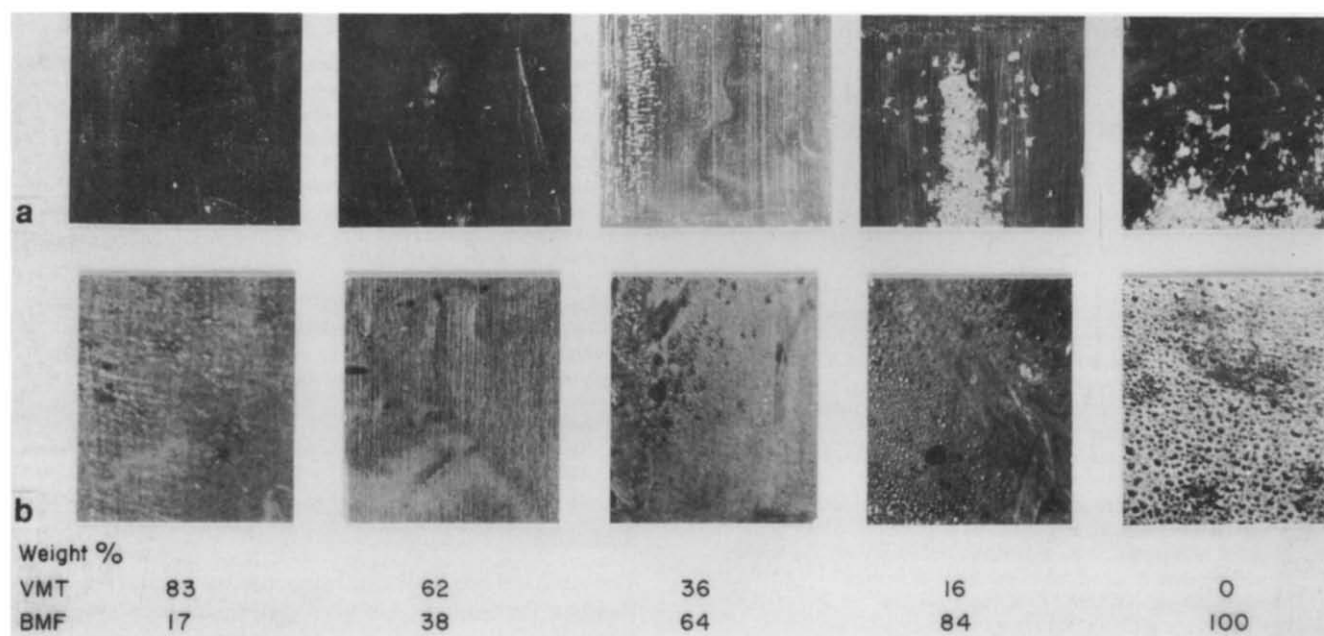


Fig. 7 Degradation of VMT/BMF blend coatings on (a) aluminium and (b) mild steel after immersion in salt water for 168 h at 30°C

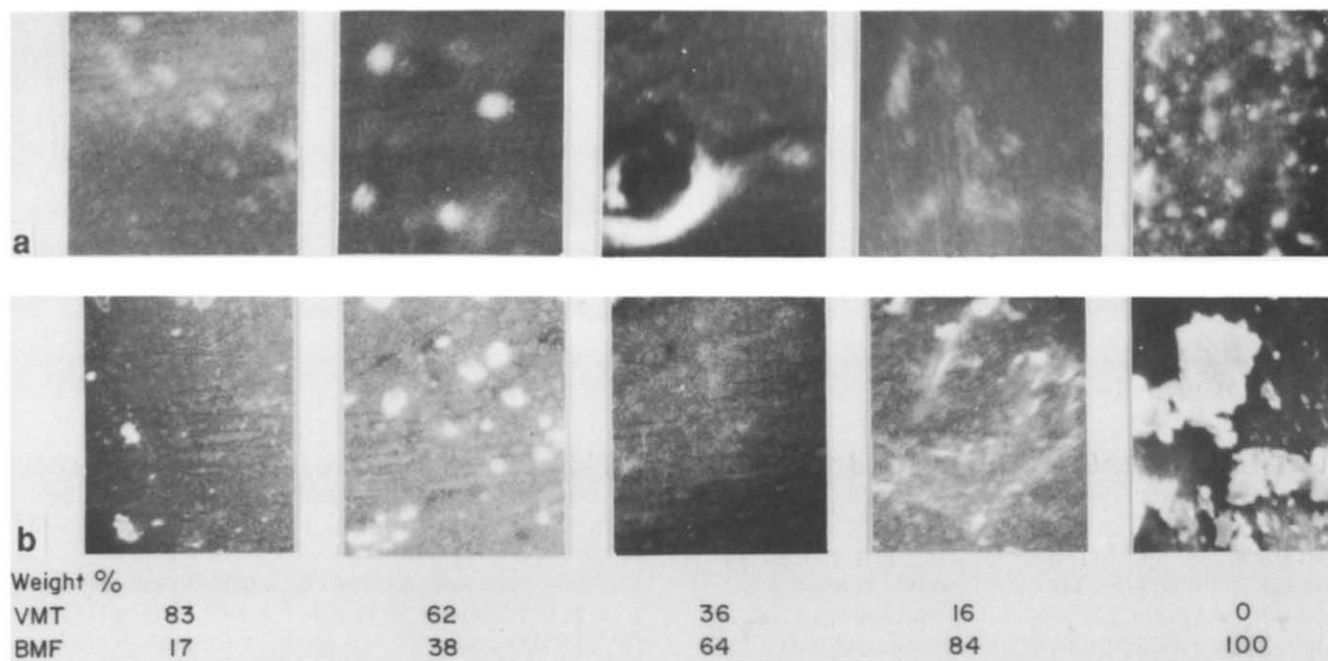


Fig. 8 Scanning electron micrographs of weathered VMT/BMF coatings on (a) aluminium and (b) mild steel (magnification $\times 6400$)

corrosion of the metal surface and the cumulative effect of interaction between the coating and the metal surface appear to determine adhesion of the coating immediately after immersion in water. SEM micrographs of peeled surfaces show that for VMT/BMF blends, the adhesive mode of failure becomes prominent as the crosslinked structure of the blend increases. IR spectral shifts of the chlorine and ester groups of VMT and of the ether group of BMF suggest that chemical interaction between these groups and the metal took place when blend-coated panels were stoved at an elevated temperature for a long period.

From the present study of blend curing efficiency and coating properties (adhesion, salt water immersion and weathering resistance) it may be concluded that the 36:64 VMT/BMF blend composition appears to produce the best balance of properties as a surface coating formulation for both untreated and acetone-washed Al and mild steel, combining the property advantages of both component polymers.

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