Chapter II

LITERATURE SURVEY

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2.1. Carbon Steel Alloy:

Carbon steel is among the most widely utilized engineering materials for structural applications. As such, the corrosion performance of carbon steel under a wide variety of environmental conditions has been examined.

Huang and coworkers [(70)] found that the corrosion rate of carbon steel in the sea bottom sediment with sulfate reducing bacteria (SRB) could be as high as ten times of that in sea bottom sediment without SRB. It was found that SRB alters the polarization behavior of carbon steel significantly because the environment is acidified due to the activity of SRB hence, the corrosion of steel is accelerated.

Wan et al. [(71)] studied atmospheric corrosion of carbon steel pre-corroded by different pollutants such as sulfur dioxide, hydrogen sulfide, and nitrogen dioxide. The pre-corroded samples were further exposed at two central test stations in the country to evaluate the influence of pre-corrosion on the behavior of long term atmospheric corrosion of carbon steel. They used gravimetric measurements and rust examinations with FTIR and XRD. It was found that, among the three pollutants, NO_2 shows the strongest influence to the process.

Melchers [(72)] studied the effect of small changes in carbon content on the immersion corrosion of specimens that are made of normal commercial mild and low alloy steels. It was found that carbon content has minimal effect on kinetically controlled corrosion phase, while it does affect the anaerobic phase, with a noticeable increase in corrosion with increasing the carbon content and the water temperature. The results showed that carbon content may be influential for longer-term corrosion and for corrosion in tropical water.

Refait et al. [73] analyzed rust layers formed on steel sheet piles immersed 1m above the mud line for 25 years, the samples were analyzed by raman spectroscopy, scanning electron microscopy and elemental X- ray mappings (Fe, S, O). It was found that the rust layers consist of three main strata, the inner one is composed of magnetite, the intermediate one of iron (III) oxyhydroxides, and the outer one of hydrozysulphate green rust GR (SO_4^{2-}). Simulations of GRs formation in solutions having large Cl^- / SO_4^{2-} ratios reveal that the hydroxysulphate GR (SO_4^{2-}) was obtained instead of the hydroxychloride GR (Cl^-), as demonstrated by X-ray diffraction and transmission Mössbauer spectroscopy analysis. It was concluded that the GR, acting like a "sulphate pump", may favor the colonization of the rust layers by sulphate reducing bacteria.

Vera et al. [74] analyzed the effect of the exposure angle on the corrosion rate of mild steel. They exposed the test samples to marine environment at 0°, 30°, 45° and 90° inclination to determine the effects of contaminants on the protective characteristics of the rusts. SEM-EDX analysis and polarization curves were performed on the weathered samples. The results demonstrated that the exposure angle influences the corrosion rate, as also the morphology of the rust, but it has no effect on rust composition.

Rodriguez et al. [75] carried out a study in order to identify the various elements, which make up the layer of rust that, produced on carbon steel upon exposure to the atmosphere in the Canary Islands, Spain. XRD and SEM analysis were used in order to identify and describe the various corrosion products produced over different areas on the islands: rural, urban, marine and marine-industrial. The main product found was akaganeite, which is typical of marine areas, followed closely by lepidocrocite, goethite and magnetite. It has been found that the protective capacity of corrosion products increases over the first year of exposure and then levels off. They used a hyperbolic law to model the protective effect of the corrosion products layer and an extremely good regressive values are obtained.

Kobus [(76)] presented the analysis of corrosion rates of carbon steel, zinc, aluminum and copper after long-term exposition as a function of time and environmental parameters. The analysis was performed for one year exposition of metals on three sites (urban / industrial, urban and rural atmosphere) in Poland. They used the equation $C= At^n$, (where C is corrosion rate after t years, and A is corrosion rate after the first year of exposition) to determine exponent n for the different metals and sites from log-log plots.

Almeida et al. [(77)] summarized the results obtained in the MICAT project for mild steel specimens exposed to 22 rural and urban atmospheres in the Ibero-American region for 1 to 4 years. The Authors determined the steel corrosion product layers (SCPLs) chemically and morphologically. It was observed that some climatological factors could affect steel corrosion rates and SCPL properties. The results obtained showed that the different atmospheres don't affect the corrosion rates significantly, but the only common characteristic of these atmospheres is the increase in SCPLs protectiveness with exposure time.

Corrosion of mild steel in water has been evaluated by Mercer and Lumbad [78]. Long term tests (up to 150 days) have been carried out on steel specimens at temperatures between 5 and 90°C in different corrosive media: distilled water, solutions containing 35 ppm Cl ions, tap water, and seawater. It was found that the increase in chloride content increases the mass loss of the specimens whereas, the hardness salts decreases it during the test period.

Roy [79] has concluded that the rate of corrosion of steel in seawater increases significantly with the increase in temperature and aeration whereas, the rate was found to decrease with increasing carbon content and with the change from dry blasting to wet blasting. Field tests in tropical seawater were carried out at 2 and 12 m depths, and it was observed that no significant difference in corrosion rate is found at these two depths.

Bera and leistikow [80] exposed low carbon steel to various sulfate and chloride - containing aqueous solutions in order to evaluate the corrosion behavior of carbon steel. The results obtained from electrochemical measurements showed that the corrosion rate is highly dependent on salt brine composition, pH, and temperature. Also, active metal dissolution leads to formation of shallow pits as surface corrosion phenomenon. Thus, the application of electrochemical techniques, under non-polarized as well as under potentiodynamic conditions, proved to be suitable for fast qualitative testing of the influence of various environmental parameters on steel corrosion.

Chernov [81] established a quantitative relationship between physico - chemical parameters of seawater and steel corrosion. The author proposed a model describing the variation in the corrosion of steel with time as a function of the aggressiveness of seawater. It was found that, the corrosion of all low - alloy steels are in virtual agreement and diminish with exposure time. Also they observed that this reduction is more vigorous in water with a higher oxygen concentration and temperature.

2.2. EPDM/PE Blends:

Thermoplastic elastomers (TPE) based on blends of polyethylene (PE) with selected grades of polyolefin elastomers like ethylene propylene diene rubber (EPDM) have drawn considerable attention in recent years because of their ease of processing, low cost, and promising physical properties.

Chandra et al. [82] evaluated the dynamic mechanical properties of vinyloxyaminosilane grafted ethylene propylene diene terpolymer / linear low density polyethylene (EPDM - g - VOS / LLDPE) blends with special reference to the effect of blend ratio. It has been found that increasing the proportion of LLDPE in the blends decreases the Tg values and increases the storage modulus (È) due to the increase in crystallinity. Also, they found that mechanical properties such as tensile strength and hardness increase with increasing the concentration of LLDPE in the blends, whereas the values of elongation at break are decreased.

The effects of morphology and molecular composition on the electrical strength of blends of linear and branched polyethylenes were investigated. Hosier et al. [83] used three crystallization procedures to modify the morphology.They observed that the morphologies depend strongly on the crystallization temperature but are largely insensitive to changes in the molecular constitution of the blend. It has been found that the electrical strength, as measured by ramp testing, is dependent on the morphology of the material but is not influenced by significant changes in the molecular composition of the blend.

Chul and Kim [84] investigated the effect of different applied levels of carbon black on the mechanical and electrical properties of ethylene propylene diene terpolymer (EPDM) compounds. The results obtained showed that tensile strength increases with increasing carbon balck loading, while tracking resistance and dielectric properties of EPDM compounds decrease with adding conductive carbon blacks.

Bartczak et al. [85] investigated the mechanical response of rubber modified high density polyethylene (HDPE). The rubbers were either ethylene propylene copolymer (EPDM) or ethylene octane copolymer (EOR) blended with HDPE at volume fractions of up to 0.22. The incorporation of rubber into HDPE does not substantially change its crystallinity but produces special forms of preferential crystallization around the rubber particles. It was found that the sharp toughness threshold in the rubber-modified HDPE results from a specific micromorphology of the crystalline component of HDPE surrounding the rubber particles. The PE crystallites of approximately 0.3 μm length perpendicular to the interface are found to be oriented with their planes parallel to the particle interfaces. Materials of this constitution have an isotropic plastic resistance of only about half that of randomly oriented crystallites.

Crosslinking of low and high density polyethylene blends with ethylene - propylene diene terpolymer (EPDM) with dicumyl peroxide (DCP) in presence of coagent (zn diacrylate) was investigated by Viksne et al. [86]. It was found that such blends exhibit an increase in adhesion against steel and improved strength - deformation properties in comparison with similar blends crosslinked with DCP alone. It was assumed that this improvement in peel strength is due to the optimal ratio between oxidative crosslinking and oxidative degradation for this blend. Another reason was suggested that the increase of interfacial adhesion may be caused by possible formation of graft copolymer.

Kim et al. [(87)] investigated rheological, thermal, and mechanical properties of low density polyethylene blended with ethylene propylene diene terpolymer. They also studied the crystalline structure and morphology of the blends. It was found that the properties and morphology of the blend are dependent on the blend compositions, and that the LDPE / EPDM blends of 90/10 composition by weight % show miscibility in the rheological sense.

Blends of LDPE, LLDPE, and EPDM were prepared by Manzur et al. [(88)] to investigate the effect of elastomer on the physical properties of the blends. It was found that the structure exhibited by stress-strain curve of the polyethylenes blends is reduced with the addition of the elastomeric phase and the ultimate properties increase because the amorphous phase becomes softer and reduces its capability to transmit the applied stress to the crystalline particles.

Jia and chen [(89)] studied the dependence of electrical resistvities on the temperature for different LDPE / EPDM blends filled with carbon black. It was found that polymer-carbon black interaction could greatly influences the electrical resistivity and temperature relations of the polymer composites. It was observed that the polymer blends filled with oxidized carbon black have a very weak negative temperature coefficient (NTC) effect, which is due to the strong polymer-filler interactions.

Kim et al. [90] have concluded that dynamically vulcanized EPDM / LLDPE blends showed higher tensile strength and modulus in comparison to the linear blends, this was attributed to chemical crosslinking of EPDM. Also, it was found that on increasing EPDM content, elongation at break increased in linear blends while it decreased in dynamically vulcanized ones. They observed that the crystal structure of LLDPE is not changed by the inclusion of EPDM or the dynamic vulcanization process.

Slusarski et al. [91] have prepared blend of ethylene-propylene diene rubber (EPDM) and low density polyethylene (LDPE) crosslinked by dicumyl peroxide (DCP). The morphology, reactivity of the components, and crystallinity of the blend have been studied. It was found that (LDPE) decreases the crosslinking efficiency of EPDM by DCP and it also, influences the mechanical properties of the blend. They concluded that PE particles are solvated by the elastomer matrix.

Comparative studies on the dynamic and static vulcanization for blends of polyethylene (PE) and ethylene-propylene-diene monomer rubber (EPDM) are reported. Ghosh et al. [92] found that, at 298 K, both the tensile strength and elongation at break are higher for vulcanizates obtained statically compared to those obtained dynamically while the corresponding modulus values follow the opposite trend.

2.3. Corrosion Protection by Polymer Coatings:

Polymeric materials are widely used as corrosion-protection coatings, that protect steel by providing a barrier to oxygen, water, and corrosive ions.

Polymeric coatings are found to perform very well in many areas of applications.

Bourgés and Savadogo [93] stated that recycled polyethylene terephthalate (PET) can be used for steel corrosion protection. The results obtained showed that recycled PET presents very good adhesion on steel. It was found that temperature and UV exposure induce only insignificant loss of adhesion, and that UV radiation causes a slight degradation of PET.

Möller et al. [94] examined low density polyethylene film after 15 years of service as an air and water vapor barrier. They used tensile testing, size exclusion chromatography (SEC), oxygen induction temperature measurements, UV and FTIR spectroscopy, and MALDI mass spectrometry to examine the differently aged parts of the LDPE film. It was found that the film loses about 75% of its initial antioxidant concentration, but no degradation of the polymer is observed, i.e., LDPE film has not been affected by ageing.

Golozar [95] et al. applied high - density polyethylene (HDPE) coating on plain carbon steel after treating the surface mechanically and then chemically. Effects of various variables, such as surface roughness, prephosphating treatment, addition of stabilizer, and the role of curing time and temperature were investigated. The results obtained revealed that pure HDPE can be coated on plain carbon steel with a good performance. It was further observed that an addition of 0.5 wt. % of heat stabilizer to HDPE powder increases the performance of the produced coating significantly. This was evidenced by the measurements of adhesion, ductility, and corrosion resistance in sulfuric acid, sodium hydroxide, ferric chloride, water, and salt spray, as well as scanning electron microscopic examinations.

The corrosion resistance and weatherability of color polyethylene coated steel pipe was investigated by Takayuki and coworkers [96]. Polyethylene coated steel pipe shows excellent performance in terms of corrosion resistance because of its barrier effect to water, high electrical resistance, as well as its superior mechanical properties. The weatherability of the color polyethylene coating depends upon not only antioxidant content but also on ultraviolet screening properties with pigments and ultraviolet absorbers. It was found that the newly developed color polyethylene coated steel pipe has corrosion resistance in severe corrosion environments as well as weatherability for more than 20 years.

Yoshihiro et al. [97] developed a new polyethylene - coated steel pipe of superior characteristics for use in pipelines operating at 80°C. It was found that when the newly developed polyethylene coating blended with a special antioxidant stabilizer, it demonstrates high durability at 80°C in various acclerated degradation tests. When the coating is reinforced with an adhesive (of high elevated-temperature adhesive strength) and an epoxy primer, it displays tight adhesion to the steel pipe at elevated temperature. Also, they found that the polyethylene-coated steel pipe exhibits excellent corrosion resistance in underground piping tests lasting for about 3 years at an accelerated test temperature of 100°C.

Anderson et al. [98] studied the degradation of different polyethylenes, low density polyethylene (LDPE), linear low-density polyethylene (LLDPE), and high-density polyethylene (HDPE) (with and without antioxidants, at different oxygen concentrations in the polymer granulates) in extrusion coating processing. It was found that the degradation starts in the extruder where, primary radicals are formed which are subjected to the auto – oxidation when oxygen is present. In the extruder, crosslinking or chain scissions reactions are dominating for LDPE at low and high melt temperatures respectively, while chain scission is overall dominating for the more linear LLDPE and HDPE resins. A number of degradation products are identified, for example, aldhydes and organic acids which are present in homologous series.

Chang [99] and coworkers discussed the application of X-ray techniques including X-ray scattering and X-ray absorption spectroscopy for a nondestructive evaluation of steel corrosion beneath an organic coating. The capability of the X-ray techniques for the nondestructive evaluation has been demonstrated, and chemical species of Fe oxides beneath the corroded organic coating were identified by the X-ray techniques.

Idla et al [100] characterized electrically conductive polymer, (poly pyrrole) films on mild steel with atomic force microscopy (AFM) and X-ray photoelectron spectroscopy (XPS), they observed that thin Ppy films (200 nm) are highly adhesive, whereas thicker films (7.5 μm) can easily be spilled off from the metal. The AFM study of the interface between the metal and the polymer showed areas of different morphology, which suggests that both adhesive and cohesive failure of the polymer film occur.

Kishikawa et al. [101] developed polypropylene coated steel pipe for high temperature service and they discussed its mechanical properties, thermal oxidation resistance, and corrosion resistance. The results obtained showed that low temperature embrittlement is improved with the use of block co-polymer polypropylene, while the addition of antioxidant improves thermal oxidation resistance. The developed polypropylene coating is expected to protect steel pipe from corrosion under severe conditions at more than 80° C.It was suggested that this coating will be useful for 30 years at 110° C, but for a shorter period of time at 120° C.

Polypropylene copolymer coatings have been used for the protection of the external surface of on-shore and off-shore pipelines. Guidetti et al. [102] developed new applications for polypropylene coatings, these include an insulating coating obtained with foamed polypropylene and an internal coating obtained by spraying a polypropylene adhesive powder. It was concluded that polypropylene is one of the most suitable coatings when high mechanical properties and / or heat resistance are required.

Liu et al. [103] studied the corrosion behavior of PVD coated steel in 0.5 N NaCl aqueous solution. They determined the coating porosity and localized corrosion with exposure time using the corrosion potential difference ($\Delta E_{corr.}$) between mild steel and PVD coatings, and the polarization resistance R_p, which was obtained through electrochemical impedance spectroscopy (EIS) modeling using equivalent circuits. Also, visual inspection, SEM examination, and the scanning reference electrode technique were employed to observe the corrosion progress of PVD coated steel with immersion time, in order to validate the EIS interpretation.

Miszczyk and Darowicki [104] investigated the effect of temperature cycling between 20 and 55°C, -20 and 20°C on the durability of polyvinyl, epoxy, and acrylic coating systems applied on mild steel using the impedance spectroscopy technique. Basing on the obtained results, they proposed the following mechanism of accelerated degradation, in comparison to isothermal exposure. Temperature changes induce the development of hygrothermal, thermal, or mechanical stresses in the coating in wet, dry, or frosty conditions, respectively. Then, the adhesive bond strength diminishes until the local cohesive stress reaches critical value and adhesive damages occur. This contributes to coating degradation by creation of conductive pathways in the coating as cracks filled with electrolyte. Each further temperature changes can cause propagation of defects and increase their accumulation over time. It was concluded that macroscopic failure occurs when a specific limit of accumulated damage is reached.

Kralji et al. [105] studied the inhibition of steel corrosion by polyaniline (PANI) coatings. These coatings were electrosynthesised on steel samples using sulphuric and phosphoric acids as supporting electrolytes. They investigated the protective properties of PANI coatings by monitoring open-circuit potential vs. time, and by applying electrochemical impedance spectroscopy. Comparing $PANISO_4$ and$PANIPO_4$ layers, the latter proved to offer better protection, i.e., OCP is stabilized in the passive region for a longer period of time. It was also shown that the thicker layers offer protection for longer time. Electrochemical impedance spectroscopy measurements showed that a PANI layer in the EM state prevents the dissolution of steel, and the capacitive behavior of PANI prevails in the passive potential region. However, at the potential values of LE state, PANI does not prevent the metal dissolution process but only hinders it slightly.

Tan and Blackwood [106] investigated corrosion protection by multi-layered conducting polymer coatings. They used combinations of polyaniline

(PANI) and polypyrrole (PPY) which were galvanostatically deposited onto both carbon steel and stainless steel. Potentiodynamic polarization was used to assess the ability of these copolymers to provide an effective barrier to corrosion in chloride environments. The performance of these multilayered coatings on carbon steel are not sufficiently better than for single PANI coatings to justify their more complicated deposition procedures. However, in the case of stainless steel the multilayered coatings proved to be significantly better than previously reported single PANI coatings, especially at protecting against pitting-corrosion. Scanning-electronic-microscopy observations and adhesion measurements, a long with the electrochemical data suggested that the ability of a conducting polymer film to act as electronic and chemical barriers is more important in providing corrosion protection than its ability to act as a physical barrier.

Fahlman et al. (107) examined the early stages of interface formation between iron and the emeraldine base (EB) form of polyaniline, the results obtained showed that iron diffuses into the polymer film all the way to the outer surface, forming metal-polymer complexes with the emeraldine base. Electrochemical potentiodynamic measurements in salt solutions demonstrated the corrosion protection ability of EB coat on steel with a reduction in corrosion current and a shift to more noble potentials for the EB-coated steel coupons.

Santos et al. (108) concluded that corrosion of steel could be prevented using the conductive polymers as a protective layer. They observed that the protective action of polyaniline films promotes a change in the corrosion potential to more positive values (= 100 mV) for carbon steel, and that for stainless steel (= 270 mV), they attributed this change to the formation of a passivated layer which blocks the corrosion progress. Using weight loss method, it was found that the inhibition efficiency of PANI films for corrosion processes was almost 100% for both kinds of the used steel.

Talo et al. [109] used electrochemical methods to investigate the efficiency of polyaniline / epoxy blend coatings on mild steel in 0.6 M NaCl and 0.1 M HCl aqueous solutions. It was found that the corrosion protective performance was characterized by a permanent shift of corrosion potential with about 500 mV to the noble direction and by a decrease of five orders of magnitude in the redox current.

Kotnarowska [110] described the influence of environmental factors such as: ultraviolet radiation, thermal shocks, aggressive media (5% water solutions of: sulphuric acids, potassium hydroxide and sodium chloride) as well as weathering on the course of mechanical characteristics of an epoxide coating. It was stated that ageing processes that occur in the epoxide coating cause deterioration of its mechanical properties, such as: hardness, tensile, strength as well as unit elongation.

The potentiostatic polarization techniques have been used by Popa et al.[111] to characterize the organic coatings electrodeposited on carbon steel. The experiments were conducted in stagnant, natural aerated 3% NaCl solution under ambient conditions. They used the electrochemical parameters obtained from the anodic polarization curves for the characterization of the electrodeposited epoxy coatings. It was established that, these coatings present good performances characterized by low porosity and low water uptake. Also, the coatings present a good adhesion to the carbon steel substrates during the exposure period (60 days), and no degradation or delamination process can be observed.

Zhang et al. [112] obtained two epoxy resins, EP and EPA, with similar backbone structure but they have different water affinity. They used these two resins to study the effect of the polymeric structure on the corrosion protection of the coatings. They found that the free volume in EPA is larger than that in EP, while water sorption of the former is only half that of the latter. Therefore, water affinity of the resin is more important in determining water sorption of the resin than the free volume. The cross-sectional area of water passage at the coating / metal interface (A_w) was estimated using the electrochemical impedance spectroscopy and it was compared with that in the resin matrix (A_{cs}). It was found that for EPA, the A_w is much less than A_{cs}, which suggests a significant narrowing of water passage at the coating / metal interface. This narrowing, which resulted from the formation of a hydrophobic layer can greatly improve the corrosion protection of the coating.

Almeida et al. [113] studied new paint systems that are less harmful to the environment and to human than traditional solvent-borne systems, but they have identical anti-corrosion characteristics. The study had involved coatings exposure to 7 natural atmospheres and different laboratory accelerated tests, and the set was completed with scanning electron microscopy (SEM) observations, energy dispersive spectrometry analysis, adhesion tests, water up-take, and electrochemical measurements. It has been concluded that water-borne acrylic paint systems pigmented with zinc phosphate show deficient behavior in marine atmospheres, but better behavior in industrial atmospheres. However, in marine atmospheres, water-borne epoxy paint systems, including zinc-rich primers, together with epoxy and epoxy-polyurethane high-solids paint systems, present the most efficient anti-corrosion behavior.

Drob et al. [114] used the anodic polarization curves and the time dependence of paint capacitance and paint resistance to evaluate the protective properties of epoxy films on carbon steel substrate. The coatings were formed using four deposition techniques (brushings, immersion, cathodic, and anodic electrodeposition) with the aim to determine the effect of deposition type on the anticorrosive performances of epoxy coating. The results obtained from the anodic polarization measurements show nobler corrosion potentials and smaller dissolution current densities for the carbon steel in the presence of electrodeposited films in comparison with epoxy coatings applied by brush or with the immersion technique. Also, the values of the porosity, water uptake, and ionic transport through the film emphasize the higher performances of the electrodeposited films characterized by uniformity, porosity absence, low water permeability, and few conductive pathways.

Jang and Kim [115] introduced silane coupling agents N - B aminoethyl amino propyltrimethoxy silane (AAPS), Y-glycidoxypropyltrimethoxy silane (GPS), and bis {3-(trimethoxisilyl)-1-phenyl propyl} tetrasulfide (RC-2) as primers onto an epoxy / steel system to suppress steel corrosion at elevated temperature and in humid conditions. Silane coupling agents and epoxy were coated onto the steel surface using the solution casting method. The polymer degradation was investigated by fourier transform infrared with reflection absorption spectroscopy (FTIR-RAS) and scanning electron microscopy (SEM). It was found that, compared to various silane treated epoxy/steel systems, the AAPS-treated epoxy/steel (AAPS / epoxy = 6 : 4) system suppresses steel corrosion at 400°C for 10 min in air and for 5 days at 60°C in 100 % relative humidity. This was explained by the formation of Si-O-Si linkage and Fe-O-Si bond on the steel surface, which are resistant to water diffusion and thermally stable at elevated temperature.

Miskovic et al. [116] carried out a.c. impedance measurements on epoxy-resin electrocoated steel to determine the pore resistance of the organic film as a function of exposure time to 3 % sodium chloride solution. Gravimetric liquid sorption experiments were used to evaluate water uptake inside the coating. The results were interpreted in terms of a model in which water rapidly penetrates both the macropores (that present as defects in the external portion of the coating) and extrafine capillaries formed by the polymer net. They used optical microscopy to estimate the number, dimensions, and shape of the pores through the film. It was shown that conduction through the coating depends only on conduction through the macropores, although the quantity of electrolyte inside the macropores is only one tenth of that inside the polymer net.

Cory [117] suggested that an effective mean to protect steel pipes against corrosion is by applying ethylene-acrylic acid copolymer films as protective coatings. Field studies and laboratory testing showed that polymer coated pipe resists chemical and abrasive attack longer than pipe protected by other methods.

Dhanalakshmi et al. [118] concluded that a single coat of polymer-polymer composite (PPC) can be recommended for protecting the steel structures from chemical and marine environment instead of using conventional three or four coat systems. They prepared epoxy polyamide, chlorinated rubber, and silicon resin based PPC coatings. Similarly, the multicoat system based on these three layers were applied on steel surfaces with the same thickness. The chemical resistance properties of the multicoat system were compared with the one coat of PPC coating. Also the electrochemical behavior for both of them was studied using electrode potential and a.c. impedance measurements. The results obtained showed that the PPC system displays better protective properties and longer service life than the multicoat system.

Organosilane compounds are among the most extensively studied compounds in the field of adhesion enhancement of organic coatings on an inorganic substrate. Its performance has been related to its ability to form a "bridging effect" at the interfacial region. However, the work done by Harun et al. [(119)] proved that variations in molecular orientation and the chemical state of the compound functionality can give unexpected results on its ability to enhance adhesion of certain coatings to a substrate. They studied the nature of 3 - aminopropyl triethoxysilane applied on mild steel substrate using X-ray photoelectron and infrared spectroscopy. It was found that, when this compound was applied under common conditions, the amine functional end of the compound appears to bond to the metallic substrate, and it may be present in the form of a non - protonated amino group or hydrogen-bonded amino group. This "wrong-way round" adsorption is shown to affect organic coating performance profoundly.

The influence of both substrate structure and roughness on the adhesion strength and corrosion resistance of carbon steel / chlorinated rubber varnish / artificial sea water systems was analyzed by Sere et al. [(120)] using electrochemical tests. Results obtained showed that the metal / coating adhesion increases with increasing the steel roughness, this was attributed to the enlargement of the number of active sites for metal / coating bonding. It was observed that the substrate structure doesn't produce significant changes in corrosion resistance.