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Research Paper

Effect of Anti Corrosive Coatings To Steel - A State of Art Report

Engineering

KEYWORDS : Corrosion, Bond Strength, Durability, Permeability, Coatings, Chemical attack

R.VARALAKSHMI Research Scholar, Department of Civil Engineering, Kalasalingam University, Krishnankoil Tamilnadu, India

S.N.RAMASWAMY Associate Professor, Department of Civil Engineering, Kalasalingam University, Krishnankoil Tamilnadu, India

ABSTRACT

The prime area of interest of present Civil Engineering World is the production of durable concrete so as to perform over a specified period under the influence of degradation factor. In rapid urbanization Concrete Structure with reinforcement of steel are in practice throughout the world for High rise building, tunnels, Railway Sleepers, Highways, Bridges, Dams, Reservoir, turbo generator foundation, Nuclear Powe rplant etc.

Among all durability problems, the Corrosion of steel is a major problem and environmental factors are not given due weightage in Codal provision or in design software. As such corrosion preventive measures to steel are imperative. Although several corrosion preventive methods are available, coating to steel rebars is an effective tool to prevent corrosion. There are several types of Coating available for steel rebars. This review paper focuses on the various studies of application of Anticorrosive Coatings to steel bar and thereby comprehensive review of studies on epoxies, metallic coatings, cement based and other coatings is presented.

INTRODUCTION

Steel – reinforced concrete is widely used in Construction activities. The corrosion of steel reinforcing bars in the concrete causes deterioration and limits the life of Concrete Structure. To understand the magnitude/seriousness of the problem one can easily realize by considering the fact that the cost of Corrosion in India is about 2 Lakh Crores annually. Globally corrosion results in loss of 24,000 Million Ton of Steel every minute according to INTL. CONF "Corrosion in Infrastructure and Chemical Industries (CICI-2012)" held at Institute of Technology and Management (ITM) Universe, Vadodora and Times of India – Dec – 5, 2012, Vadodora edition.

Chloride attack is distinct in that the primary action of Corrosion of steel reinforcement and it is only as a consequence of this corrosion that the surrounding concrete is damaged and thereby causes deterioration of Reinforced Structures. Steel embedded in hydrating cement paste rapidly forms a thin passivity layer of oxide and gives it complete protection from reaction of oxygen and water and this state is known as passivation.. Chloride ions activate the surface of steel to form an anode, the passivated surface being the cathode initiating corrosion and its continuation is not inevitable. The consequences of corrosion of steel are (i) the products of corrosion occupy a volume several times larger than original steel result results in cracking spalling or in delamination of concrete (ii) reduces the cross sectional area of steel, thus reducing its load carrying capacity.

A mixture of methods are being implemented for Controlling Corrosion which includes concrete composition (low water/binder ratio), design and work procedure that minimizes cracking, ensuring good curing of concrete and adopting sufficient cover. Further it includes corrosion inhibitors, coatings and other surface treatments for the concrete surface as well as the reinforcement bars.

Fusion bonded epoxy and galvanizing are the most widely used systems for rebar coating. The rebar coatings are applied either in a production plant or on the construction site prior to concreting. Epoxy coating of steel is a specialized technique which can be helpful in addition to an adequate thickness of cover concrete of low permeability.

ANTI CORROSIVE COATINGS

(i) LOCAL SCENARIO (INDIA)

Venkatesan.P.etal (2006) (1) "Corrosion performance of coated reinforcing bars embedded in concrete and exposed to natural marine environment" conducted studies on Corrosion behavior of three different specially coated mild steel bars with cement polymer composite, interpenetrating polymer network coating and epoxy coating. Periodically evaluation done by open circuit potential measurements at three different levels identified as Atmospheric, High tide and Sea floor. They concluded that cement polymer composite coated rebar relatively performed well by giving less corrosion rate by impedance method after completion of 362 days exposure to natural marine environment in all the above said three levels.

Saravanan.K.et.al (2007 (2) "Performance evaluation of polyaniline pigmented epoxy coating for Corrosion protection of steel in concrete environment" analysed the performance of newly developed epoxy based coating system containing polyaniline by various techniques such as electrochemical impedance spectroscopy, Potential time studies, Cathodic disbondment test, anodic polarization study, salt spray test and chemical resistance. The Corrosion resistance was also studied by an accelerated time to cracking study. They found that the resistance of coating decreased initially and then increased due to passivating ability of polyaniline pigment in electrochemical impedance study. Also it was observed that the corrosion resistance was excellent and exhibits impermeable property against chloride attack.

Selvaraj .R. et.al (2009) (3) "Studies on the evaluation of the performance of Organic Coatings used for prevention of Corrosion of Steel bars in Concrete Structures" Conducted mechanical and accelerated test for performance of organic coating/ polymeric coatings based on different resins such as acrylic polyol-aromatic iso cyanate, polyster polyol – aromatic isocyanate, acrylic resin and epoxy – silicone – polyamide containing Ordinary Portland Cement or Flyash as extenders and titanium dioxide and Zinc phosphate as main pigments on rebar. They observed out of 16 coating formulations, four have been performed well as effective and durable coatings. Among coatings, two pack system such as epoxy – silicone – polyamide resin with zinc phosphate pigment and flyash performed excellent and rated as best one.

Krishnaveni.K.et.al (2009) (4) "Corrosion Resistance of electrodeposited Ni-B and Ni-B-Si_3 N_4 Composite Coatings" compared the corrosion resistance of EDNi-B-Si_3N_4 composite coating both as plated and heat treated with its plain concrete part. The EDNi-B coatings were prepared with addition of dimethylamine borane and ED Ni-B-Si_3N_4 composite coatings with Si_3N_4 particles and applied in mildsteel disc 30mm dia.They examined the structural and Morphological characteristics of ED Ni-B and Ni-B-Si_3N_4 composite coatings wing XRD & SEM and Corrosion resistances were evaluated by potentio dynamic polarization and EIS studies.The study reveals that incorporation of Si_3N_4 particles in EDNi-B matrix decreases metallic lusture, increases the surface roughness, alters chemical composition and reduces the cracks in coating. Also the marginal improvement in corrosion resistance observed for EDNi-B-Si_3N_4 composite coatings compared to its plain counterpart could have resulted from the decrease in effective metallic area prone to corrosion.

Aritrakhan and Tata Satya Teja (2010) (5) "An Experimental study on prevention of Reinforcement Corrosion in Concrete Structures" conducted studies on concrete concast with coated rebar using polystrene, red-oxide, Black Japan and Aluminium paints and examined the bond strength between reinforcement and concrete. They observed that final potential shown by 8ml polystyrene/ ml of benzene was more positive than any other coating whereas Black Japan coating shows most negative due to predominant role of volume of carbon particles.They suggested that polystyrene coating and red-oxide coating performed better.

Dhoke.S.K. et.al (2012) (6) "Effect of Nano-Zinc oxide Particles on the performance behaviour of water borne polyurethane composite coatings" have performed a research on Nano-composite coating which incorporates Nano-Zno pigments (0.1% and 1.0% by Wt.) in a water borne polyurethane dispersion (WPUD) to rebar. They conducted coated mild steel substrate to salt-spray, humidity and accelerated UV-weathering. Also study on mechanical-properties like scratch resistance, Abrasion resistance and pencil hardness were taken-up. FTIR technique used to investigate interaction between nano-Zno_2 particles and polymer functionalities. Moreover SEM, AFM were conducted. They revealed that the results showed an improvement in the Corrosion, UV and mechanical properties of the coatings at lower concentration (0.1% by wt.) indicating the positive effect of addition of nano-Zno particles in the coatings. They also stated that Nano-Zno can serve as a good barrier pigment and UV blocking agent in WPUD, however optimizing their concentration and improved dispersion in polymer matrix can further improve the performance properties of coating.

Rasmika Patel-et.al (2014) (7) "Studies on Flame Retardant Polyurethanes and their Blends with Epoxy resin for Nano-composite and Nano-coating applicants" undergone an experimental research wherein flame retardant polyurethane were synthesized by reacting a diphosphorus based monomer, bisphenol – A bis (hydroxyl phenyl phosphate) (BABHPP) with different diisocyanates and polyurethane were characterized using chemical and instrumental analysis techniques like elemental analysis, FTIR, GPC techniques. Polybends were prepared by mixing the polyurethane with conventional DGEBA resin in different proportions and used for coating purpose. Nano composites were prepared using organic modified montmorillonite clay. Thermal, flame retardant, impact, tensile properties of nano composites, various coating performances and properties were determined. They stated that polybends and nano composites show better properties compare to the neat polyurethane.

Senthil Nathan K.P.et.al (2014) (8) "Experimental study on Corrosion Prevention in R.C. slabs" analysed about the preventing of corrosion in RC slab using anticorrosive agent of Nito-zinc primer coated rebar. M20 mix R.C.C. slab size 600mm x 500mmx50mm were cast and coated by metallic zinc: Epoxy resin – 3:2 (by weight). It was noticed that weight loss on rebar was taken-up and it was noticed that coating of rebar was 50% more effective than the uncoated rods, bond strength of coated rebar is practically same as that of uncoated bar.

Bhaumik M Patel and Hasmukh S Patel (2015) (9) "Polyurethane surface coatings derived from (Rosinified Phenolic resin – coconut alkyd resin) blends with Aliphatic and Aromatic Diisocyanates" discussed the advances in the use of renewable resources in formulations of various types of coating. Therein polyurethane prepolymers were synthesized from coconut oil based alkydresin and rosinified phenolic resin as polyol with aromatic and aliphatic diisocyanates by varying NCO/OH mole ratio. Dibutyltin dilaurate (DBTDL) and Xylene were used as Catalyst and solvent respectively. Coated panels were examined for drying time, Adhesion test, Flexibility Test, Scratch hardness, pencil hardness, impact resistance and chemical resistance by standard methods. Results of Scratch hardness, pencil hardness and resistance against chemicals are higher in case of PU films prepared from Tolune dissocyanate (TDI) as compared with PU films prepared from Isophorone diisocyanate (IPDI).

Ekalvya Calla and Modi S.C. (2000) (10) "Long life Protection of Steel by Zinc – Aluminium Coating formed by Thermal spray process" dealt with current Status of thermal sprayed zinc and aluminium coatings for corrosion protection. Thermal spray coatings are applied by twin wire arc process. The Al-Zn pseudo alloy coatings contain two phases, one is zinc rcih and other is aluminium rich. The Zinc rich phase offers cathodic protection by its sacrificial action while the aluminium – rich phase provides protection by barrier action. They noted that aluminium – zinc pseudo alloy coatings offer better alternative to the conventional aluminium and zinc coatings for corrosion protection.

(ii) GLOBAL SCENERIO :

DeniseM.Lenz.et.al (2003) (11) "Application of polypyrrole/ TiO_2 composite films as corrosion protection of Mild Steel" conducted study about anticorrosion protection of polypyrrole (ppy) on AISI 1010 steel by incorporation of TiO_2 pigment into the PPy matrix. Morphology of composite film was studied by SEM and distribution of the pigment within the polymeric matrix by X-ray photo electron spectroscopy (XPS). They stated that PPy/TiO_2 composite showed a considerable improvement in anticorrosion properties after undergoing salt spray and weight loss tests. It has been recommended that above composite films can be applied as a primary coating replacing the phosphatized layers on mild steel.

Gerald G.Miller. et.al. (2003) (12) " Effect of Epoxy coating thickness on Bond strength of Reinforcing bars" undergone a study about effect of epoxy coating thickness on bond strength with coating thickness ranging from 160 to 510um. They had test bars with three different deformation patterns viz. Bar had diagonal ribs oriented 70^0 to longitudinal axis, bar had diagonal ribs oriented 60^0 to longitudinal axis and bar had ribs perpendicular to the longitudinal axis. They observed that epoxy coating with 160 to 510um thick reduce the bond strength of deformed bars and it was

suggested that the maximum – allowable coating thickness should be increased from 300 um to 420 um and layerbars meeting the requirements of ASTM.

Griselda Guidoni and Marcela Vazquez (2004) (13)" " An Evaluation of rust conversion coatings in simulated reinforced concrete pore solutions "analysed the performance of Rebars coated with two different rust conversion coatings. Rust conversion coatings was a one-component epoxy paint containing inhibiting additives based on barium metaboarate and other coating was formulated on an alkyd base and incorporated colour pigments. On evaluation it was reported that neither of above coating improved significantly the behavior of steel against corrosion and suggested that the application of this type of coating not recommended when repairing mainly due to high alkalinity of concrete.

Souza, Maria Eliziance Pires et.al. (2007) (14) "Comparative Behaviour in terms of wear and corrosion resistance of Galvanized and Zinc-iron coated steels "studied about the behaviour of Galvanized and Zinc iron coated electroplated steel and compared in terms of electro chemical behaviour by polarization tests, open circuit potential and friction co-efficient during sliding and loss of mass after sliding. The surface morphology was studied by SEM. They confirmed that wear – corrosion behavior of hot – dip galvanized coatings was superior to that of Zn-Fe samples.

Akin Akinci (2008) (15) "The salt spray corrosion of polymer coatings on steel" performed the test of salt spray corrosion of steel coated with an epoxy – polyester layer at difference thickness from 50 to 180um and then cured at 200^0C for 20min in liquid petroleum gas atmosphere. By comparing different pre- treatment of mild steel, sand blasting, phosphating and epoxy- polyester coating, it was clearly evident that corrosion resistance is higher in the phosphating system and that double layer corrosion resistance is higher than that of single layer in salt system. Also salt spray measurements indicate that epoxy- polyester polymer blend system is more suitable than unblasting and unphosphating as far as protection from a chloride environment is concerned.

Akinyemi O.O (2009) (16) "Effect of 0.05M Nacl on corrosion of coated reinforcing steel in concrete" conducted an experimental study of corrosion protection of re bars coated with (i) bitumen (ii) enamel paint and (iii) local anti-rust paint. The study reveals the protection offered by these coatings in sodium chloride solution. They expressed that enamel paint coating has the best protection followed by bitumen coating and finally local anti-rust paint coating.

Xianming Shi.et.al (2009) (17) "Effect of Nanoparticles on the anticorrosion and mechanical properties of epoxy coating" carried out experiment about Homogeneous epoxy coatings containing nano particles of SiO_2, Zn, Fe_20_3 and halloysite clay and curing of a fully mixed epoxy slurry diluted by acetone. Surface morphology by SEM and AFM were carried out. Effect of incorporating various nano particles was investigated by potentio dynamic polarization and Electrochemical impedance spectroscopy. They informed that SiO_2 nano particles were found to significantly improve the micro structure of coating matrix and enhanced both anticorrosive performance and young's modulus of epoxy coating.

Shokry.H. (2009) (18) "Corrosion protection of mild steel electrode by electrochemical polymerization of acrylamide" implemented a research regarding polyacrylamide (PAA) film was electro synthesized on mild steel by cyclic voltammetry using Ce (iv) salt-oxalic acid initiator system. The capacity of PAA film to protect mild steel from corrosion in an Nacl aqueous solution was investigated by potentio dynamic polarization curves and electrochemical impedance spectroscopy. They revealed that corrosion resistance of PAA coated mild steel significantly higher than that of uncoated steel.

Goncalves.G.S.et.al. (2011) (19) "Alkyd coatings containing Polyanilines for Corrosion protection of mild steel" carried out study to investigate the performance of anticorrosion coatings obtained from alkyd paints containing polyaniline and polyaniline derivatives. Alkyd paints containing different types of CP (doped and undoped with different acids) Undoped polyaniline (PAni EB) and polyanilines doped with Hcl (PAni HCl), p-toluenesulfonic acid (PAni pTSA), dodecylben zenesulfonic acid (PAni DBSA), or cam phorsulfonic acid (PAni CSA) were obtained. Poly (O-ethoxyaniline) (PE pTSA) were doped with p-TSA. They stated that this study reinforce the possibility of protecting carbon steel against corrosion through the formation of a protective layer of oxides using coating which contain electro active polymers.

Panek.J-et.al (2011) (20) "The corrosion resistance of Zinc-Nickel composite coatings" estimated the corrosion resistance of composite Zn+ Ni and (Ni+Zn+Ni) /Zn coatings by salt spray test, electrochemical methods and grazing incidence x-ray diffraction method. They reported that the corrosion resistance of Zinc-nickel coatings is dependent on Ni content and it grows with increase in Ni percentage in coatings .The higher corrosion resistance could be attributed to the presence of inter metallic Ni_2 Zn phase.

Akinci.A and Yilmaz.F (2011) (21) "The effect of epoxy polyester sealing of sprayed – metal coatings for additional corrosion protection" investigated about salt spray testing of epoxy polyester top-coating applied on Zn-sprayed, Al-sprayed and 85Zn +15 Al sprayed steel samples and thickness of top coating ranging from 120 to 210 um. The Corrosion test was performed with salt solution for over 2000h and damages noted. It was evident that the corrosion resistance of Al-sprayed top coated surfaces was better than other systems and hence durable one.

Dongming Yan et.al (2012) (22) "Effect of chemically reactive enamel coating on bonding strength at steel /mortar interface" tested the mortar cylinder each with one steel rod embedded in tension to characterize the bonding strength at the steel/ mortar interfaced. It was observed that bond strength between a smooth steel rod and mortar can be increased by as such as seven times when the rod is coated with a mixture of 50% enamel and 50% calcium silicate particles due to increased surface roughness. Also the failure loads of rods coated with reactive enamel increase with concrete aging time with a maximum load reached upto atleast 97 days, whereas failure loads of uncoated rods decreased slightly after 28 days of curing.

El-shazly.A.H and Al.Turaif H.A. (2012) (23) "Improving the corrosion Resistance of Buried Steel by using polyaniline coating" investigated the possibility of improving corrosion resistance of buried steel by coating it with polyaniline (PANi) layer. Coatings are characterized by X-ray photoelectron spectroscopy and Ellipsometric analysis. The formed PANi layer was examined for its corrosion resistance while coupled with Stainless Steel cathode and buried

in sand containing different known amounts of moisture, salt (Nacl) and sulphuric acid (H_2SO_4). using potentio dynamic examination test. PANi layer exhibits improvements corrosion resistance against Nacl, H_2SO_4 and water by factors upto 1.88, 1.89 and 1.54 respectively.

Jorge.S.et.al (2012) (24) "Influence of Anticorrosive coatings on the bond of steel rebars to repair mortars" conducted an experimental study to assess the bond of anticorrosive coating rebars to the repair mortar by conducting pull-out tests while rehabilitation of reinforced structures. Therein Repair mortar's composition are of three types viz. (i) cementitious grout, sand, synthetic resins, silica fume and polyamide fibres (ii) Fibre-reinforced plain cement concrete and (iii) Hydraulic binder, synthetic resins, siliceous sand, silica fume and synthetic fibres. Similarly Anticorrosive rebar coating comprises of cement based modified epoxy resins,cementitious mineral corrosion protection and synthetic resin in aqueous dispersion, corrosion inhibition pigments, mineral filler. Finally they have stated that it was advisable to always apply cementitious coatings to plain rebars whereas it should be avoided for ribbed bars since in this case, the loss of average bond strength due to coatings if found to be 40%.

Baldissera. A.F. and Ferreira C.A. (2012) (25) "Coatings based on electronic conducting polymers for corrosion protection of metals" carried out investigation about the corrosion protection of mild steel by a novel epoxy resin (EP) – based coating system containing polyaniline (PAni) as anticorrosive. The corrosion behavior of mild steel samples coated with anEP/PAni-EB(Emeraldine base), EP/PAni-ES(Emeraldine salt) ,EP/SPAN (PAni sulfonated), EP/Pani-fibers, EP/Phozn(Zincphosphate), EP/Chrozn (Zinc chromate) or EP/charge was investigated in 3.5% Nacl solution by electro chemical impedance spectroscopy and concluded that coating containing SPAN was found to have best performance in protection.

Fujian Tang. et.al (2012) (26) "Corrosion Resistance and mechanism of steel rebar coated with three types of enamel" undergone studies about corrosion resistance of steel bar with 3 different enamel coatings (i) pure enamel (ii) enamel mixed with 50% Calcium silicate (iii) inner layer coated with pure enamel and outer layer by mixed enamel were investigated in 3.5 wt% Nacl solution by Electro chemical impedance spectroscopy and performance was compared with that of FBE coated and uncoated rebars. They suggested that the pure and double enamel coatings performed better than the mixed enamel coating due to their dense microstructures with isolated pores.

Mariusz Ksiazek (2013) (27) "The intensity of Corrosion processes influenced by tensile stress for reinforcing steel covered with sulphur polymer composite applied as industrial waste material" invgestigated above the corrosion rate of steel bars covered with polymer sulphur composites applied as industrial waste material coating and exposed to tensile stress was attempted. Potentio static investigation reveals that significant reduction of corrosion rate in covering sample was deserved.

Ilkhani Ahamed (2013) (28) "Corroson protection of carbon steel by using Zinc-rich inorganic water based silicate coatings comprising different amounts of nano silica" dealt with evaluation of corrosion behaviour of water based inorganic zinc-rich coatings consisting of different contents nanosilica in potassium silicate and also zincs dust applied on steel substrates and cured for 168 hours. Evlauation done by electrochemical impedence spectroscopy (EIS), Corrosion potential measurement and salt spray test and concluded that increment of nanosio$_2$ in coating formulations led to shorten the curing time while on other hand gave acceptable results in corrosion test. Incorporation of SiO_2 + zinc increased barrier protection stage.

Rita M.Figueria.et.al (2013) (29) "Corrosion protection of Hot Dip Galvanized Steel in Mortar" studied about corrosion behaviour of hot dip galvanized steel (HDGS) using an electrochemical system to measure the macrocell current density (designed one). Therein HDGS bars are coated with different organic inorganic hybrid films (OIH) embedded in mortar during 70 days. Urea silicate OIH gelmatrices were prepared by a reaction between the isocyanate group of the derived siloxane (ICPTES) with four different di-amino functionalized polyether with different molecular weights, with and without Cr(III) ions.It has been suggested to performed above coating system in situ so as to study of response to aggressive situations.

Chang.K.C.et.al. (2014) (30) "Advanced anticorrosive coatings prepared from electro active polyimide/graphene nano composites with synergistic effects of redox catalytic capability and gas barrier properties" studied the EPI/EPGN coatings. In this study electroactive polyimide (EPI) /graphene nano composite (EPGN) coatings were prepared by thermal imidization and the structure and electro activity of the EPGNmaterials were investigated by FTIR and CV. TEM studies were taken-up to observe the dispersion capability of the Carboxyl-graphene nano sheets in EPI matrix. They concluded that Nano composites consisting of EPI matrix and well dispersed grapheme nanosheets were found to exhibit excellent anticorrosive properties resulted from enhanced gas barrier properties.

Kunrang wang.et.al (2014) (31) "Study on polymer modified cement based coating with healing effect on Rusty carbon steel"studied about the anti corrosion properties of polymer emulsion modified cement – based coating with healing effect on Carbon steel by change of linear polarization resistance and electro chemical impedance spectroscopy techniques to measure inhibitive and curvative effect of electrodes painted with coating in 3.5% Nacl solution. Therein four groups of coating applied viz. (i) Epoxy emulsion modified heavy calcium carbonate coating (HYG), (ii) Epoxy emulsion modified cement based coating (HYC), (iii) Fluoride acrylic emulsion modified cement based coating (FBC) and (iv) anti rust pigments and rust converters added to third one (FBC-RC) and concluded that inhibitive ability of cement based coating with fluoride acrylic emulsion is superior to that of the coating with epoxy emulsion.

Xiaofeipei.et.al (2015) (32) "Development length of steel reinforcement with corrosion protection cementitious coatings" carried out modified pullout test to assess the bond strength and development length of steel rebars coated with cementitious capillary crystalline water proofing material (CCCW). A self reacting invested T.Shaped beam was designed to stimulate stress conditions of flexural structural members and tests were conducted at 7 days and 90 days after casting to investigate the curing effect on bond. They concluded that development length of reinforcing steel without any coating was less than the calculated design development length by 65% and 60% for 15m and 20m bars respectively. Also CCCW coated bars showed lower bond strength than uncoated bars and respective bond factor was determined.

3.CONCLUSION:

The review revealed the following research needs.

There are several types of coating available for steel rebars including fusion bonded epoxy which is used world wide. All the coatings that are developed based on solvent base and are not green coating. Therefore in this research work an emphasize will be made to develop Cost effective, eco-friendly anticorrosive coatings. In the present investigation the study is to be carried out based on green anticorrosive coatings for steel rebar in concrete structure. Several formulations will be made with various types of pigments (Flexibility additives, Anti sagging), Fillers (Silica fume, Micro silica, clay, flyash, OPC, Rice husk ash), inhibitor. (Zinc phosphate, Sodium Phosphate) with water based binders such as OPC based and polyurethane based. Out of above two or three best coatings will be selected based on the several tests in accordance with ASTM.

As such the successful formulation of effective waterborne anticorrosive coating is now a global concern requiring extensive Research and Development work.

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