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Synthesis of anticorrosive and flame-retardant coating based on turmeric (Curcuma longa) and magnesium hydroxide

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Abstract

The green corrosion inhibitor is used in epoxy coating system by extraction of turmeric in dimethyl formamide (DMF). The major component extracted is curcumin. Three concentrations have been studied for anticorrosive performance i.e., X, 2X and 4X. Among this X based concentration showed the best performance. Magnesium hydroxide $Mg(OH)_2$ has been treated with 3-glycidoxypropyltrimethoxysilane (GPTMS). It was added into coating formulation at three concentrations namely 5%, 7% and 10% (w/w). The best anticorrosive performance has been observed for 5% concentration. As the concentration increases the anticorrosive performance decreases but flame retardancy increases. The 7% $Mg(OH)_2$ concentration has been combine studied with turmeric X concentration. It is observed that combination of extract with $Mg(OH)_2$ gives good anticorrosive performance as well as flame retardant properties. The anticorrosive performance is evaluated by salt spray and electrochemical impedance spectroscopy (EIS) and flame retardancy is evaluated by Limiting oxygen index (LOI) and UL-94 study.

Keywords: Magnesium hydroxide; turmeric; anticorrosive; flame retardant; surface functionalization

1. Introduction

Coating has been used in various industries i.e., automobile, aerospace, marine etc. In such industry the coating has to bear various different atmospheric and performance conditions (Suay et al. 2003; Zhao et al. 2010; Ekin et al. 2007) and to improve its performance various modifications has been done and depending on that coating can be categories as anticorrosive coating, flame retardant coating, anti-icing coating, superhydrophobic coating, antimicrobial coating etc. (Ahmad et al., 1999; Wang et al., 2006; Xiong et al., 2014)

The corrosion protection of organic coatings can be improved by various methods such anticorrosive pigments, conductive polymers, corrosion inhibitors etc. (Zubielewic and Gnot 2004; Sitaram et al., 1997; Mekeridis et al., 2012). Along with these synthetic materials, the natural products are also under studies nowadays for anticorrosive performance. Various plant extract, roots, leaves etc. has been studied for anticorrosive performance. (Amitha Rani and Basu, 2012; Al-Otaibi et al., 2014; Umoren et al., 2016).

Flame retardancy is another important segment. An organic coating has conventionally studied with halogenated flame retardant but they are having some limitation and hazardous in nature hence substitute of it comes into picture. (Liang et al., 2013; Lu and Hamerton, 2002)

It is proven in the literature; the functionalization improves the performance as compared to plain coating. The zinc oxide (ZnO) particles by 3-

glycidoxypropyltrimethoxysilane (GPTMS) coating shows the improvement in polyurethane coating. $ZnO-Al_2O_3$ fly ash functionalization with amino silane improves the anticorrosive performance of polyesteramide coating. ZnO modification with 3-Aminopropyltrimethoxysilane (APTMS) has shown improvement in anticorrosive and antimicrobial performance of polyesteramide coatings. (Kathalewar et al., 2013; More and Mhaske, 2016; Siyanbola et al, 2013)

Here in this study, turmeric extract has been prepared using dimethylformamide (DMF) as solvent. The extract has been made in three different concentrations namely X, 2X and 4X. The extract has been added as solvent system in epoxy-amine coating system. In the next section, magnesium hydroxide has been treated with GPTMS to introduce oxirane functionality on the surface. The treated magnesium hydroxide ($Mg(OH)_2$) has been added into in epoxy-amine coating system at three different concentration namely 5%, 7% and 10% (w/w) of total binder system. In the last part synergistic effect of $Mg(OH)_2$ and turmeric extract has been studied in coating for anticorrosive and flame retardancy performance.[1-10]

2. Experimental

2.1 Materials

Turmeric powder is obtained from local market with brand name 'Everest Turmeric Powder'. $Mg(OH)_2$, DMF, Toluene obtained from S.D. Fine India Pvt. GPTMS is obtained from alfa aesar. Epoxy resin is obtained from Grand Polycoat Pvt. Ltd. used as base resin and amine is used as hardener obtained from Dow Company Pvt. Ltd. and it is cycloaliphatic based amine.

2.2 Extraction of turmeric

For the extraction, the turmeric is used as such without any purification. The 15 g of turmeric powder has been taken into the beaker. The 75 ml of DMF solvent is added into the same. The mixture has been shaking well for the proper mixing of powder and solvent to make sure that each particle should be properly wet by the solvent. Then the beaker kept as such without disturbing for 24 hours at room temperature. After completion of 24 hours, the extract in solution formed has been separated from the powder by filtration. The filtrate collected has been used as such as a solvent for coating system and it is named as X concentration. For 2X and 4X based concentration, 30 g of turmeric powder has been added to 75 ml solvent and for 4X concentration 60 gm of turmeric powder has been added to 75 ml DMF.

2.3 Surface treatment of magnesium hydroxide

The surface treatment of $Mg(OH)_2$ is done using GPTMS as silane precursor and toluene as solvent media. Firstly 10 g of $Mg(OH)_2$ has been weighed in round bottom flask. The 50 ml of toluene is added into the same and ultrasonicated for 30 minutes. This will break the aggregates of $Mg(OH)_2$ as well as ensures dispersion of the same in solvent media. Then 1 g of GPTMS has been added into the same and stir on magnetic stirrer at room temperature for 1 hour. Then the temperature has been increased till the reflux occurs and reaction is mentioned at that temperature for 24 hours. The treated $Mg(OH)_2$ is separated from solvent media by filtration and ethanol washing is given to remove excess, unreacted GPTMS. The product obtained is dried in oven at 60ºC. (More and Mhaske 2016) [11-15]

2.4 Synthesis and application of coating

The epoxy resin is used as base resin and amine is used as a hardener. For epoxy-amine plain system, the total batch has been calculated considering the weight of resin and hardener. With considering our resin system, for 10 g of total batch, 7.69 g of epoxy is required and 2.31g of amine is required as hardener. Hence firstly required quantity of epoxy resin weighed. The 10 g of DMF solvent is added into the same. The quantity of solvent kept constant in all formulation for plain turmeric based system i.e., for 10 g of batch 10 g of solvent has been used. The amine hardener is added into the same and mixed properly. Then coating is applied on mild steel panels. For turmeric based system, the 10 g extract has been used in the batch instead of plain solvent and same procedure is followed as above. For magnesium hydroxide-based system, 5%, 7% and 10% concentration has been used in the batch. The epoxy resin has been taken; the adequate quantity of solvent has been added, the magnesium hydroxide is added and the mixture is stirred on high-speed stirrer for the proper dispersion of magnesium hydroxide in epoxy resin. The mixture is stirred for 3 hours and ensure about the proper mixing and dispersion has been takes place. The required quantity of hardener and remaining quantity of solvent has been added into the same and the panel is applied. For combination, the procedure mentioned for magnesium hydroxide has been followed, for 10 g batch, 10 g extract used as solvent system firstly and the remaining solvent is plain DMF is used. The formulations of batches represented in Table 1.

Table 1. Formulations of batches

Sr. No.	Batch code	Turmeric concentration	Treated $Mg(OH)_2$ concentration
1.	Batch 1	-	-
2.	Batch 2	X	-
3.	Batch 3	2X	-
4	Batch 4	4X	-
5.	Batch 5	-	5%
6.	Batch 6	-	7%
7.	Batch 7	-	10%
8.	Batch 8	X	7%

2.5 Characterization

The turmeric extract, $Mg(OH)_2$ and treated $Mg(OH)_2$ and their respective coatings has been characterized by ATR-FTIR(Bruker, japan) method. The X-Ray diffraction analysis (XRD) is performed with 2θ diffraction CuKa radiation 5º to 90º. UV visible analysis has been performed on UV-Visible absorber instrument for the wavelength range of 700 nm to 200 nm with water as a media. Gloss has been calculated with digital glossmeter at 60º. The salt spray analysis has been performed with ASTM B 117 for 1000 hours with 5% sodium chloride solution as electrolyte. The samples are evaluated for photographic reference. The EIS analysis has been performed Versa STAT-3 instrument (AMETEK, Princeton Applied Research, Oak Ridge, TN) with saturated calomel as reference electrode, platinum electrode as counter electrode. Coated panel is works as working electrode. The area of exposure of the coating to electrolyte i.e., 3.5% sodium chloride solution is 7 cm^2. The test has been done at 0 hours and after immersion in 3.5% sodium chloride solution for 125 hours. The bode plot of the coatings is measured. The adhesion of the coating to metal surface was measured by (ASTM D 3359). The X cut method is used, by making cuts and applying transparent cellophane tape. Once the tape is removed, check for area of coating removed with tape. The rating is given with 5A for no peeling to 0A to removal beyond X cut. The scratch hardness is measured with scratch hardness tester with varying the load and coating is evaluated. The impact resistance is done with (ASTM D 2794) falling dart impact test with load 1.36 kg and maximum height of falling is 60 cm. Both forward and backward impact resistance is measured and samples are evaluated for any crack formation, loss of adhesion etc. The flexibility test is done with conical mandrel (ASTM D 522) and formation of crack and length of the crack formed is evaluated. The pencil hardness (ASTM D 3363) is determined for the pencil range of 6B to 6H. The coating is evaluated for any loss of adhesion, peeling etc. The acid and alkali resistance has been checked with 5% HCl and 5% NaOH aqueous solution and spot test is conducted (ASTM D 1308) for the duration of 24 hours. The solvent resistance (ASTM D 4752) is measured by solvent rub test with the xylene and MEK as a solvent. The limiting oxygen index (LOI) is minimum concentration of oxygen required in flowing mixture of oxygen and nitrogen that is sufficient to start the combustion of tested material. The LOI test has been conducted, to study the flame-retardant properties of the material. Another test to study the flame-retardant properties is UL-94 vertical burning test (ASTM D 1356). The samples were tested having dimension 8 cm× 1 cm× 1cm. It was placed vertical and ignited by using LPG burner. Thermogravimetric analysis (Perkin elemer) has been at scanning rate of 20ºC/min under nitrogen and air. The scanning has been carried out for the temperature range of 40ºC to 700ºC.[16-21]

3. Result and Discussion

3.1 %Solids Calculations

The % solid of extract has been calculated by solvent evaporation method. The weight of empty petridish has been taken as P1. The 10 g of extract has been added into the petridish and again weight has been taken as P2. The petridish has been kept in oven for vacuum drying at 55ºC for overnight. Again, the weight of petridish has been taken. The weight has been taken till the constant weight is obtained. The constant weight ensures the complete solvent evaporation. This final weight is noted down as P3.

% Solids has been calculated as,

$$\% \text{ solid} = \{(P3-P1)/(P2-P1)\} \times 100 \quad (1)$$

Hence the % solids have been calculated and represented in Table 2.

3.2 Fourier Transmission Infrared Spectroscopy (FTIR)

The result for FTIR of turmeric extract has been represented in Fig. 1. The FTIR of X concentration, 2X concentration and 4X concentration has been represented in same. FTIR of $Mg(OH)_2$ and treated $Mg(OH)_2$ has been shown in Fig. 2. Fig. 3 represents the FTIR of turmeric based coatings. Fig. 4 represents the FTIR of $Mg(OH)_2$ based coatings and also the $Mg(OH)_2$ and turmeric extract combinations.

Table 2. % Solids calculation

Sr. No.	Concentration	% Solids
1	X concentration	2.25%
2	2X concentration	3.25%
3	4X concentration	7%

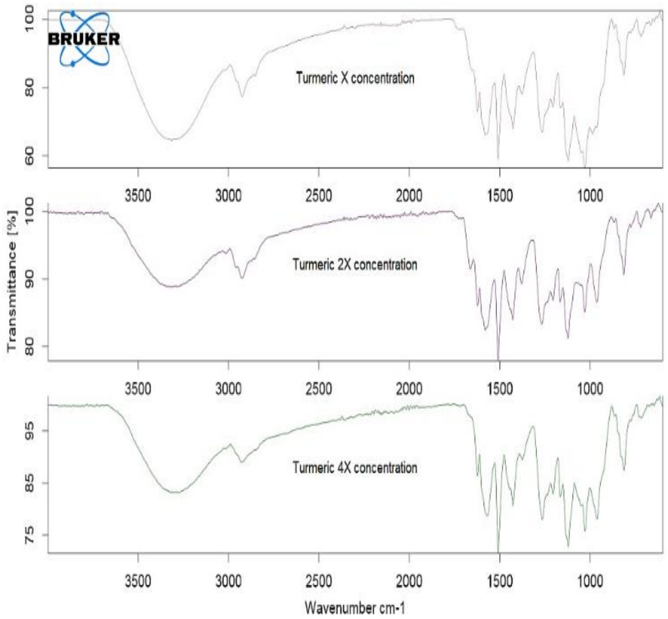

Fig. 1. FTIR of turmeric extract

The major constituent and which is also important from our study point of view is curcumin. The structure of the same is represented in Fig. 5. So according to figure if we compare the FTIR spectrum, the peak at ~3320 cm^{-1} represents the –OH stretching. The symmetrical stretching of C-O-C groups appeared at ~1050 cm^{-1} corresponds to alkyl aryl ether. The stretching frequency of –C=O groups is appeared at ~1120 cm^{-1}. The alkyl aryl ether gives the stretching frequency of asymmetrical C-O-C group at ~1205 cm^{-1}. This confirms the curcumin has been present in turmeric extract which we have obtained. (Johnsirani et al., 2013)

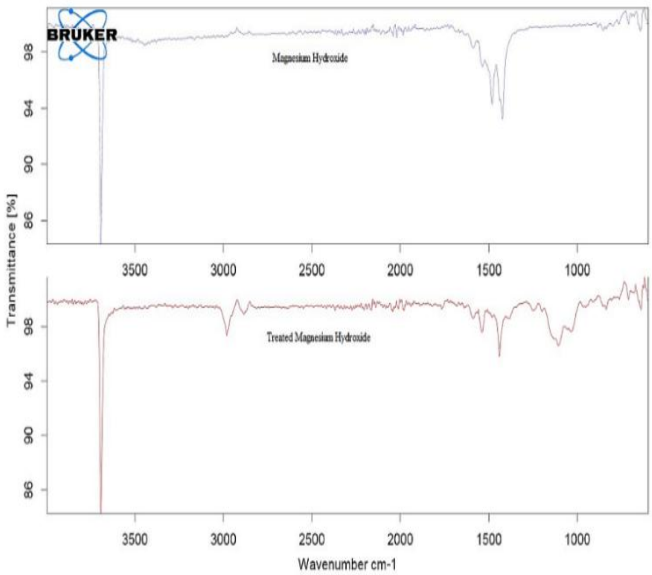

Fig. 2. FTIR of $Mg(OH)_2$ and treated $Mg(OH)_2$

In $Mg(OH)_2$ and treated $Mg(OH)_2$ the sharp peak at 3690 cm^{-1} is due to –OH band stretch of $Mg(OH)_2$ crystal structure.(Qiu et al., 2003) In treated sample the broadening is observed at ~1070-1110 cm^{-1} is due to Si-O linkage. The peak observed at 1265-1270 cm^{-1} and at 920 cm^{-1} is due to the oxirane ring of GPTMS. These peaks are absent in untreated $Mg(OH)_2$ which confirms the surface treatment has been taken place successfully.

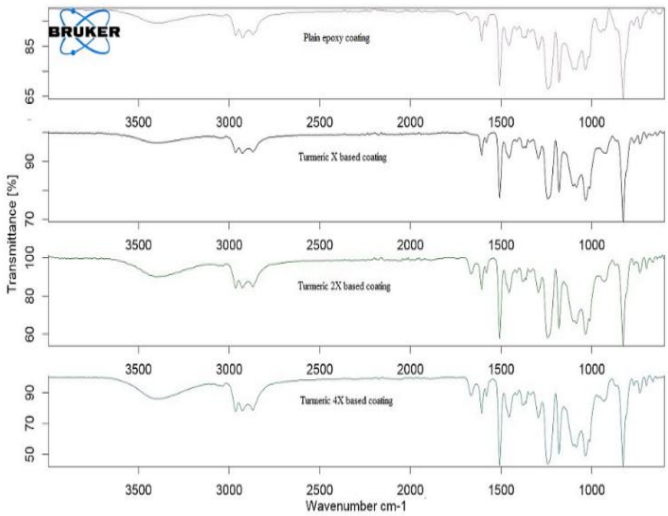

Fig. 3. FTIR of turmeric based coating

In Fig. 3, the turmeric functional groups are overlapping with epoxy-amine system and since the curcumin concentration is less in system the significant characteristic peak of it gets overlap with the epoxy-amine system but the broadening observed at ~ 3390-3420 cm^{-1} in turmeric system. This broadening also presents in plain epoxy-amine system but the intensity of it increases as concentration of curcumin is increases in the system. This broadening occurs in plain epoxy-amine system due to formation of –OH functionality due to reaction of epoxy with amine and ring opening of oxirane group. This broadening is increases due to interaction of curcumin with oxirane in epoxy-amine system. This increase in the intensity of this range confirms the interaction of curcumin with epoxy.

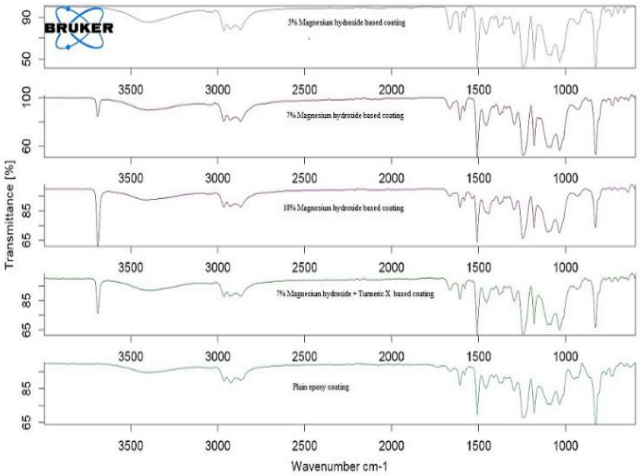

Fig. 4. FTIR of $Mg(OH)_2$ based coating

In Fig. 4, the panels based on $Mg(OH)_2$, gives characteristic peak of $Mg(OH)_2$ at 3690 cm^{-1} which confirms successfully incorporation of $Mg(OH)_2$ in coating system. All other peaks are overlapping with epoxy-amine system hence not seen predominately. The oxirane peaks of GPTMS not seen in the coated panels since GPTMS gets interact in curing system. Hence Fig. 4 confirms successful incorporation of $Mg(OH)_2$ in coating system.

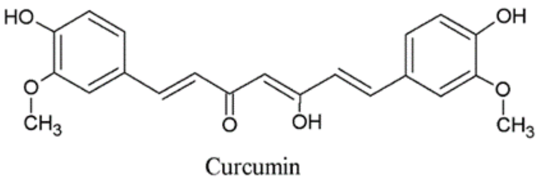

Fig. 5. Structure of curcumin

3.3 X-Ray Diffraction (XRD) Analysis

XRD analysis of plain $Mg(OH)_2$ and treated $Mg(OH)_2$ is shown in Fig. 6. As seen from the figure the % crystallinity of plain $Mg(OH)_2$ is 50.26% and for modified sample is 50.14%. The characteristic peak of $Mg(OH)_2$ observed at ~19º, ~38º, ~51º, ~58º, ~62º,~68º and ~72º. These peaks are observed in plain $Mg(OH)_2$ and modified $Mg(OH)_2$ this confirms the modification takes place successfully without affecting the core $Mg(OH)_2$ properties. The % crystallinity found to be almost equal as that of plain $Mg(OH)_2$. The slight reduces in % crystallinity is due to the silane treatment which develops the amorphous layer on the $Mg(OH)_2$ surface.

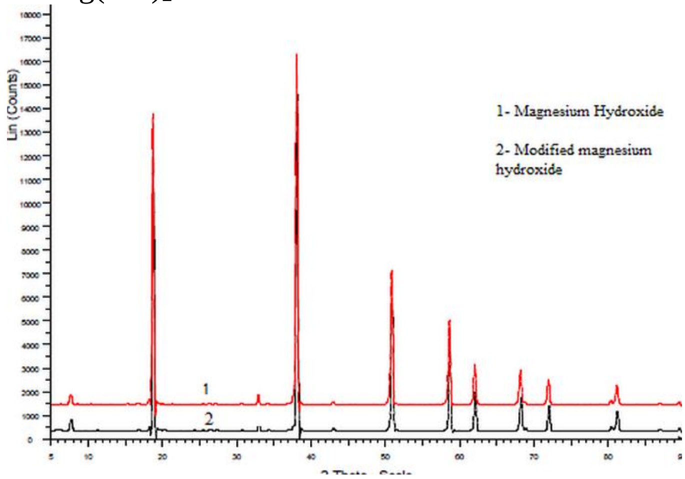

Fig. 6. XRD analysis of $Mg(OH)_2$ and treated $Mg(OH)_2$

3.4 UV-Visible Spectroscopy

The result for UV-visible spectroscopy has been shown in Fig. 7. The plain $Mg(OH)_2$ shows the peak at ~370 nm. In modified $Mg(OH)_2$ sample along with this peak, the peak observed at ~ 280 nm. This is due the surface treatment of $Mg(OH)_2$ with silane precursor. The peak at ~ 280 nm confirms the silane treatment has been taken place successfully.

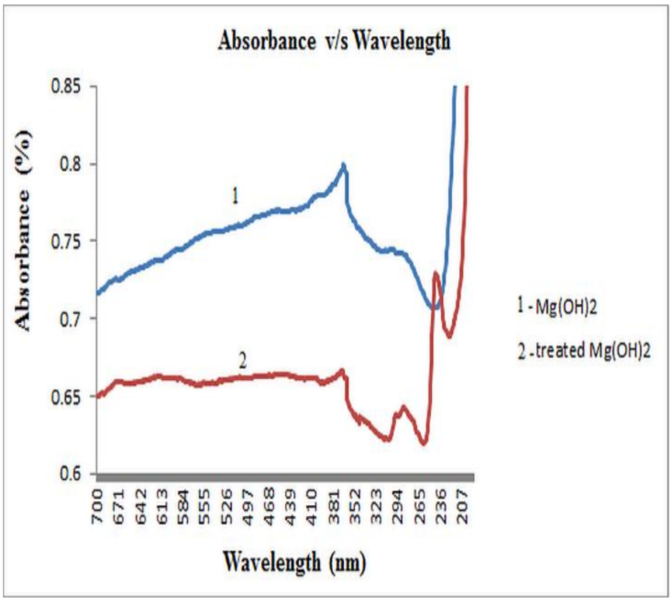

Fig. 7. UV-Visible analysis of Mg $(OH)_2$ and treated $Mg(OH)_2$

3.5 Gloss

The gloss of the coating which is measured at 60ºC is tabulated in Table 3. As seen from the table, the plain epoxy coating shows the highest gloss. With addition of turmeric extract the gloss starts decreasing. With addition of magnesium hydroxide also the gloss starts declining. As the concentration increases the gloss starts decreasing rapidly and for curcumin plus $Mg(OH)_2$ system it reaches to 73 units from highest gloss i.e., 102 for plain epoxy. This could be due to increasing the filler content which tends to decrease the gloss of the coating.

Table 3. Gloss of the coating

Sr. No.	Batch code	Gloss
1.	Batch 1	102
2.	Batch 2	99
3.	Batch 3	95
4.	Batch 4	93
5.	Batch 5	94
6.	Batch 6	85
7.	Batch 7	74
8.	Batch 8	73

Table 4. Mechanical properties of coating

Sr. No	Properties	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7	Batch 8
1.	DFT (μm)	100±05 μm	100±05 μm	100±05 μm	100±05 μm	100±05 μm	100±05 μm	100±05 μm	100±05 μm
2.	Cross hatch adhesion	5B	5B	5B	5B	5B	5B	4B	5B
3.	Scratch resistance (Kg)	3.7	3.9	4.0	3.9	3.9	4.1	3.8	4.1
4.	Pencil hardness	2H	4H	2H	2H	3H	3H	2H	3H
5.	Impact resistance (Kg-cm)	FI 81.6 BI 81.6	FI 81.6 BI 81.6	FI 81.6 BI 81.6	FI 81.6 BI 81.6	FI 81.6 BI 81.6	FI 81.6 BI 81.6	FI 81.6 FI 81.6	FI 81.6 FI 81.6
6.	Flexibility (mm)	0mm	3mm	5mm	7mm	0mm	0mm	0mm	0mm

3.6 Salt Spray Test

The salt spray analysis has been carried out firstly for the turmeric extraction-based coating without addition of $Mg(OH)_2$. The result for the same is represented in Fig. 8. As seen from the figure, with addition of turmeric extract the anticorrosive performance has been increased as compared to the plain coating. But as the extract is made more and more concentrated the anticorrosive performance starts decreasing. Hence the X concentration which gives the best result is chosen for the further studies. In the $Mg(OH)_2$systems, the best results are obtained for 5% formulation. As the concentration of $Mg(OH)_2$ increases the performance decreases. The loss of adhesion is also seen in the panels. The 10% concentration shows the worst results. They are very much less as compared to plain epoxy system also. Since the 5%, 7% and 10% concentration has been studied for $Mg(OH)_2$. The middle one has been then mixed with curcumin extract to study their combined effect. It is observed as with 7% concentration in presence of curcumin extract coating shows better performance than solely $Mg(OH)_2$7% concentration.

Fig. 8. Salt spray analysis of coating

3.7 Electrochemical Impedance Spectroscopy (EIS) Study

The EIS study results has been shown in Fig. 9 and Fig. 10. In EIS study, firstly the turmeric based coating only without addition of $Mg(OH)_2$ has been studied. It is observed as Turmeric X based coating shows highest impedance value at start and also maintained its anticorrosive behaviour after immersion in salt water. The plain epoxy shows least impedance value at 0 hours immersion. Whereas 4X based formulation's impedance value drops below plain epoxy after immersion. This means after immersion least corrosion resistance has been observed for 4X based formulation. In the next part $Mg(OH)_2$ based formulations has been studied. The highest impedance value has been observed for turmeric and $Mg(OH)_2$ combination before and after immersion. As the concentration of $Mg(OH)_2$ increases the impedance value starts dropping down. After immersion the least immersion value has been observed for 10% $Mg(OH)_2$ formulation.

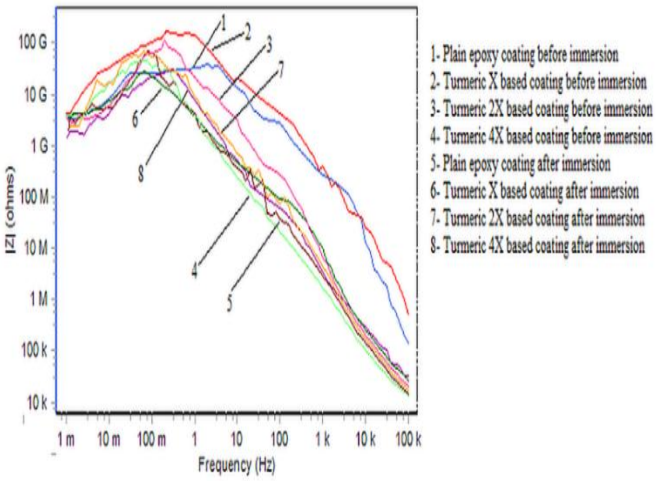

Fig. 9. EIS analysis of turmeric based coating

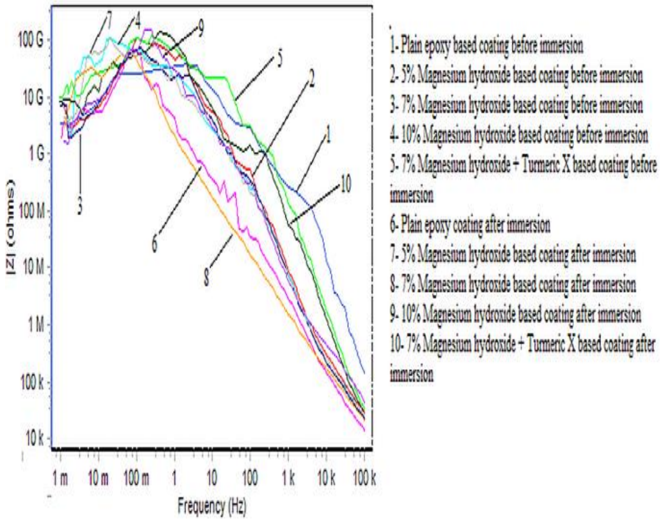

Fig. 10. EIS analysis of $Mg(OH)_2$ and $Mg(OH)_2$-turmeric combination-based coating

3.8 Anticorrosive properties

The epoxy-amine system is widely used for anticorrosive application. The system itself has good chemical resistance, adhesion, dimensional stability etc. During curing, the system develops strong three-dimensional networks which tend to improve the anticorrosive performance. With addition of turmeric extract, curcumin gets incorporated in the coating system. As seen from the Fig. 5, it is aromatic moiety, having two hydroxyl (–OH) groups present at the terminals. This –OH groups are acidic in nature. In presence of amine, it is activated and can interact with oxirane functionality of epoxy resin. Hence, with addition of turmeric extract the anticorrosive performance increases. But as the concentration of turmeric extract increase, the anticorrosive performance starts decreasing. This decrease in performance is due to free functional groups. When epoxy is mixed with hardener, sufficient amount of amine group is present in matrix which can react with epoxy. When extract is added with X concentration, the functional group of curcumin interacts with the coating system. When the 2X, 4X based concentration has been added, the quantity of free functional groups increases in the system. There is not sufficient amine and oxirane groups which can interact with the curcumin. Hence anticorrosive performance starts decreasing. With addition of 5% $Mg(OH)_2$ the anticorrosive performance was similar to plain epoxy system but as the concentration of $Mg(OH)_2$ increase in the system, the performance starts decreasing. This is due to the increase in filler content, where there is not sufficient resin to hold the film, porosity of the film increase, penetration of corrosive medium through the coating becomes easy hence the anticorrosive performance decreases. But curcumin-7% $Mg(OH)_2$ combination shows excellent anticorrosive performance. This could be due to synergetic effect of $Mg(OH)_2$ with curcumin. The curcumin will show anticorrosive performance by above mentioned mechanism and $Mg(OH)_2$ is working by sacrificial mechanism to improve the anticorrosive performance. The surface treatment of $Mg(OH)_2$ helps for its chemical interaction in epoxy-amine system during curing. The oxirane groups present on $Mg(OH)_2$ surface, gets chemically linked in epoxy-amine system. It ensures its uniform dispersion, chemical modification in coating system.

In case of curcumin, presence of lone pair on atoms presents in functional groups such as oxygen, it interacts with the vacant d orbital of ferrous metal of mild steel. Hence by donor-acceptor mechanism it tends to enhance the adhesion of the coating to metal surface. This adsorption is the major reason to enhance the anticorrosive performance of turmeric based coating. (Al-Fakih et al., 2015) In turmeric plus $Mg(OH)_2$ combination, this is the key reason to enhance the anticorrosive performance. Curcumin retains the good adhesion to the metal surface hence where in case of 7% $Mg(OH)_2$ system without addition of turmeric extract corrosion performance observed to be poor. With addition of extract the adhesion is maintained good hence performance observed to be excellent. This helps to achieve anticorrosive performance with flame retardancy simultaneously.

3.9 Mechanical properties

The result for mechanical properties of the coating is represented in Table 4. As seen from the table, the cross-hatch adhesion test passes successfully with all formulation. The inherent property of epoxy-amine system, i.e., its excellent adhesion to the metal surface tends to give good adhesion properties. In scratch resistance test and pencil hardness test, the hardness properties increase with addition of turmeric extract. The reasoning for the same is with addition of turmeric extract, curcumin gets incorporated in coating system. The curcumin is aromatic in nature hence tends to improve the hardness properties. With curcumin, the chemical interaction is occurring and it always has better performance over just physical mixing. As the concentration of extract increases in coating formulation, hardness increases further but for 4X based concentration it again drops down. This could be due to increase the concentration of curcumin further increases the brittleness of the coating which tends to decrease the performance. The $Mg(OH)_2$ addition tends to give higher scratch resistance and pencil hardness as compared to plain coating. Since it acts as a filler increase the strength of the film, creates the barrier for further scratch formation and hence performance increases. Its chemical interaction ensures its uniform distribution in coating film hence hardness values enhanced. But for 10% concentration again decrease in scratch resistance and pencil hardness is observed. Since at 10% concentration, the filler content increases to the level where there is not sufficient resin to wet the filler surface. Hence film holding capacity decreases. This leads to decrease in scratch resistance and pencil hardness values. In turmeric extract- $Mg(OH)_2$ based coatings the value of pencil hardness and scratch resistance founds to be good since synergistic effect has been observed from curcumin and $Mg(OH)_2$. All coating formulations pass forward and backward impact resistance test successfully. This proves coating has good load bearing capacity and in impact resistance no crack formation or loss of adhesion is observed on the panels. In flexibility test, the plain coating shows the no crack formation in conical mandrel test. With addition of turmeric extract the crack formation observed in flexibility test and as the concentration of turmeric extract increases the length of crack formed also increases. The reason is with addition of curcumin the aromatic moiety gets incorporated into the coating. It tends to decrease the flexible nature of the coating. In $Mg(OH)_2$ based system, again all panels pass flexibility test successfully. In turmeric- $Mg(OH)_2$ system also system passes flexibility test successfully. Hence, we can conclude that, drawback of turmeric is overcome by $Mg(OH)_2$ addition.

3.10 Chemical properties

The result for chemical properties of the coating is evaluated. It is observed that presence of acid and alkali solution does not affect the coating film for above mentioned duration. In acid and alkali resistance test, the coating remains unaffected, the gloss of the coating is maintained, it is well adhered to the metal surface, no softening or any blister formation is observed. In solvent resistance, also the coating passes successfully the rub test without any defects. The excellent chemical resistance is inherent property of epoxy-amine coating system. Addition of turmeric extract and $Mg(OH)_2$ does not affect the chemical resistance adversely.

3.11 Limiting Oxygen Index (LOI)

Table 5. LOI values of coating

Sr. No.	Batch Name	LOI values
1.	Plain epoxy	20
2.	5% Mg $(OH)_2$	23
3.	7% Mg $(OH)_2$	24
4.	10% Mg $(OH)_2$	26
5.	7% Mg $(OH)_2$ + Turmeric extract	23

The result for LOI test of the coating is tabulated in Table 5. As seen from the table the LOI values increases as the concentration of $Mg(OH)_2$ has been increases in the system. Linear relationship is observed with increasing the $Mg(OH)_2$ content and LOI values. This indicates increasing the $Mg(OH)_2$ content leads to increase the flame retardancy of the system and resistance to fire increased.

3.12 UL-94

In UL-94 test, all the specimens loaded with $Mg(OH)_2$ achieved UL-94V-1 classification whereas plain coating has UL-94V-2 classification. It is observed as the concentration of $Mg(OH)_2$ increases, the burning is occurred at the flame point only and the time required to spread the burning further also increases. This is the indication that the flame retardancy of the coating increases. In plain epoxy coating the sample after burning lost its structural stability and break down into pieces whereas in case of $Mg(OH)_2$ sample and $Mg(OH)_2$-curcumin sample also after burning does not loses its structural stability and maintain its structure after burning also this is the indication that flame retardant properties of the coating increases with addition of $Mg(OH)_2$ and $Mg(OH)_2$-turmeric combination.

3.13 Thermo-gravimetric Analysis (TGA)

The TGA analysis has been shown in Fig. 11 and char residue has been tabulated in Table 6. As seen from the result, at 700ºC the plain epoxy completely degrades with the char residue 0%. The highest residue is observed for magnesium hydroxide- turmeric combination-based coating with char residue 8.26%. Despite of modification with turmeric and magnesium hydroxide the plain epoxy shows better thermal stability at initial stages. The first stage degradation is observed due to the cracking of polymer backbone. In turmeric based coating the thermal stability improves at higher temperature due to presence of aromatic groups of curcumin which tends to increase the % residue at 700ºC. In magnesium hydroxide-based system, once polymeric backbone has been broken down, the magnesium hydroxide molecules come together and gets converted into continuous magnesium linkage. This linkage covers on the surface, hence further heat penetration can be avoided hence it saves the coating from further degradation. Hence the % char residue quantity increased in such case. In case of magnesium hydroxide-turmeric combination, the synergistic effect has been seen. Hence this system shows highest % char residue.

Table 6. TGA Analysis of coating

Sr. No.	Batch Code	%Char Residue
1.	Plain epoxy	0%
2.	Turmeric X based coating	5.69%
3.	7% Magnesium hydroxide based coating	7.51%
4.	Turmeric X + 7% Magnesium hydroxide based coating	8.26%

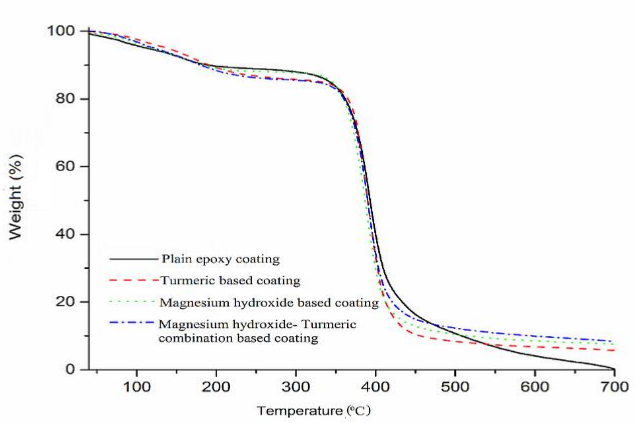

Fig. 11. TGA analysis of coating

Conclusion

Epoxy-amine coating has been modified with turmeric extract and GPTMS modified $Mg(OH)_2$. The turmeric extract contain curcumin as its component of it and gets incorporated in epoxy system. It is observed that at 2.3% solid content of extract, the highest anticorrosive performance is observed and as the concentration increases two and four times the corrosion resistance decreases. The functionalized $Mg(OH)_2$ shows best performance at 5% and as concentration increases to 7% and 10% anticorrosive performance decreases. But in flame retardancy it is observed as retardancy increases as the concentration of $Mg(OH)_2$ is increases in the system. Hence combine effect of turmeric extract and $Mg(OH)_2$ has been studied and it is observed as both anticorrosive and flame-retardant properties have been observed to be good for this formulation. Hence it is concluded that, the anticorrosive, flame retardant epoxy-amine coating is developed by turmeric extract and functionalized $Mg(OH)_2$.

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