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Hardness and adhesion performances of nanocoating on carbon steel

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Abstract. Nanocoatings industry has been aggressive in searching for cost-effective alternatives and environmental friendly approaches to manufacture products. Nanocoatings represent an engineering solution to prevent corrosion of the structural parts of ships, insulation and pipelines industries. The adhesion and hardness properties of coating affect material properties. This paper reviews $ZnO-SiO_2$ as nanopowder in nano coating formulation as the agent for new and improved coating performances. Carbon steel on type S50C used as common substrate in nanocoating industry. 3wt% ZnO and 2wt% SiO_2 addition of nanoparticles into nanocoating showed the best formulation since hardness and adhesion of nanocoating was good on carbon steel substrate. Incorporation of nanoparticles into coating increased the performances of coating.

1. Introduction

Nanocoating offer great potential for various applications due to their superior characteristics that are not typically found in conventional coatings. Nanocoating gains the most practical application in industry that is produced by usage of some components at nanoscale to obtain desired properties. Through nanocoatings, a wide variety of performance characteristics can be achieve which includes self-cleaning, self-healing, anti-microbial, UV protection, corrosion resistance and waterproofing. Nanoparticles also reduced contact tension, moisture penetration and surface roughness. On the other hand, nanoparticles increased surface area, enhanced physical, chemical, mechanical, optical and magnetic properties. Nanoparticles also absorb more resins, reduced free surface. So, the transport path of corrosive species increased and enhanced the properties and performance of nanocoating. In conventional nanocoating, when there was a drop of water on the surface of nanocoating, the contact tension was normal and the moisture can penetrate through the surface surface roughhess much more compared to nanocoating [1,2-4].

Nanocoating refers to covering nanoscale entity to produce structured materials and nanocomposite or it is related to covering materials with nano meter scale layer of 10 to 100 nm thickness. Adhesion test methods are used to establish whether the adhesion of a coating to a substrate is at a generally adequate level. The differences in adhesion ability of the coating surface can affect the results obtained with coatings having the same inherent adhesion. In these test, a lattice pattern with either six or eleven cuts in each direction is made in the film to the substrate, pressure-sensitive tape is applied over the lattice and then removed, and adhesion is evaluated by comparison with descriptions

and illustrations. If a coating is to fulfill its function of protecting or decorating a substrate, it must adhere to it. The crosscut test is a simple and easily practicable method for evaluating the adhesion of single- or multi-coat systems. For hardness study, nanoindentor was used to study the mechanical properties of nanocoatings on medium carbon steel substrate grade S50C. The type of indentor tip used was diamond Berkovich. The thickness of the nanocoating was about 0.01mm-0.03mm or 10000nm-13000nm.

2. Experimental procedures

These test methods cover procedures for assessing the adhesion of coating films to metallic substrates by applying and removing pressure-sensitive tape over cuts made in the film according to ASTM D3359. Test Method is suitable for use in the laboratory. Sharp razor blade, scalpel, knife or other cutting device having a cutting edge angle between 15 and 30° that will make either a single cut or several cuts at once. The space of the cuts 2 mm apart and make six cuts. The tape placed at the center of the grid area. To ensure good contact with the film, the tape was firmly rub with the eraser on the end of a pencil. The color under the tape is a useful indication of when good contact has been made. Within 30s of application, the tape was removed rapidly. The parameter of the nanoindentation test was tabulated in table 1. More than 10 indentation tests were conducted on each sample for accuracy.

Table 1. Parameter of Nanoindentor test

Loading rate (mN/s)	0.5
Load applied (mN)	6.0
Depth (nm)	10000

3. Results and Discussion

For the addition of nanoparticles into epoxy coating within 1-3wt% as figure 1 (a,b,c and f,g,h) small flakes of the coating are detached along edges and at intersections of cuts. The area affected is 5 to 15 % of the lattice. However, when the addition of nanoparticles too much (4-5wt%) in figure 1 (d,e and i,j), the coating has flaked along the edges and on parts of the squares. The area affected is 15 to 35 % of the lattice. In order to make sure that the coating was satisfied, coatings must adhere to the substrates. Based on figure 1 (k,l,m and n), hybrid between ZnO and SiO$_2$ was good compared to single addition of nanoparicles into epoxy coating. 3wt% of hybrid showed the best result. The edge of the cuts was completely smooth and none of the squares of the lattice is detached. Only small flakes of the coating are detached at intersections. Less than 5% of the area is affected. The coating has flaked along the edges of cuts in large ribbons and whole squares have detached in epoxy only picture without any addition of nanoparticles as figure 1 (o). The area affected is 35 to 65 % of the lattice with flaking and detachment worse than coating without addition of nanoparticles.


| (a) | (b) | (c) | (d) | (e) |

| (f) | (g) | (h) | (i) | (j) |

| (k) | (l) | (m) | (n) | (o) |
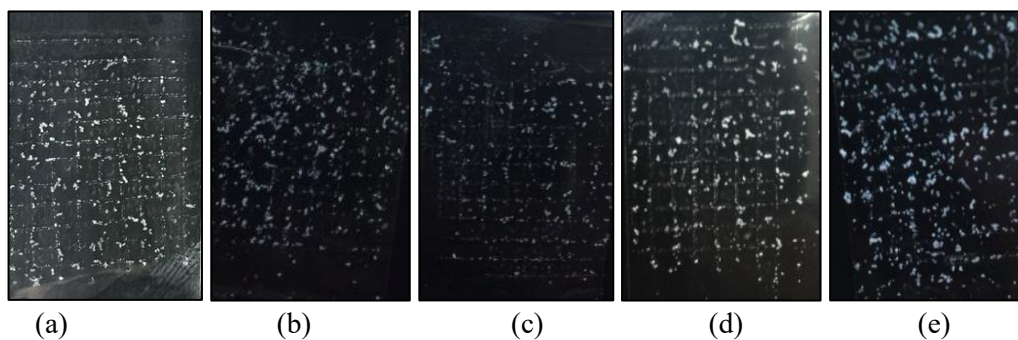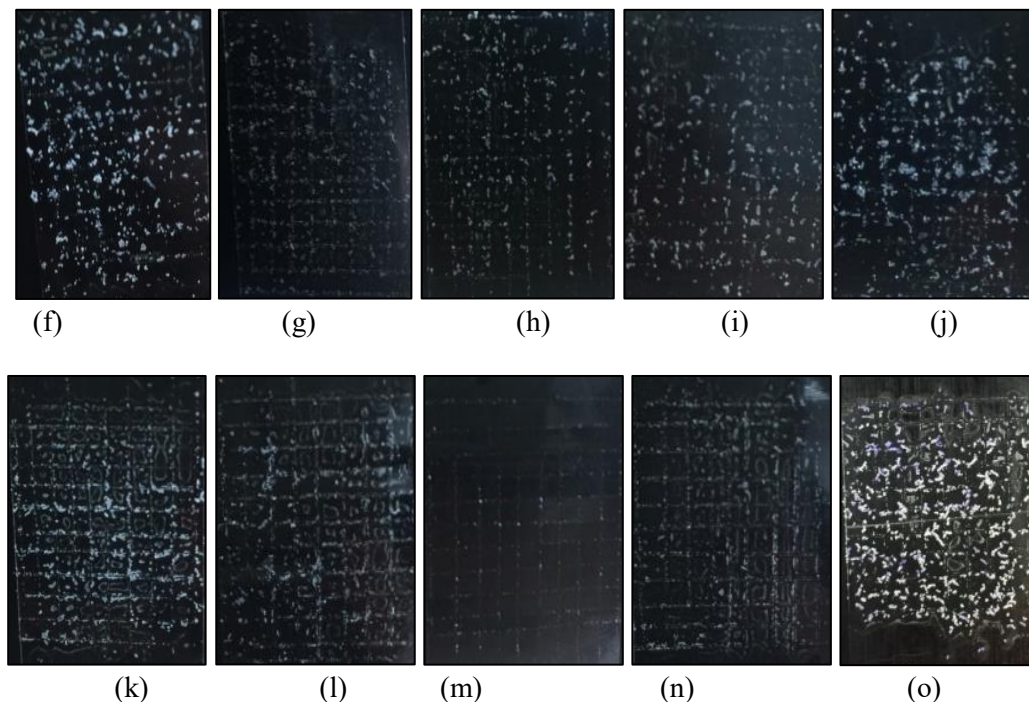
Figure1. Images of adhesion of nanocoatings. a)1wt% ZnO; b)2wt% ZnO c)3wt% ZnO; d)4wt% ZnO; e)5wt% ZnO; f)1wt% SiO_2; g)2wt% SiO_2; h)3wt% SiO_2; i)4wt% SiO_2; j)5wt% SiO_2; k)1wt% hybrid; l)2wt% hybrid; m)3wt% hybrid; n)4wt% hybrid; o)epoxy only.

Table 2. Result of hardness for different samples by Nanoindention test

Samples	Weight Percentage (%)	Hardness (GPa)
0	epoxy only	0.36461
1	$1ZnO4SiO_2$	0.39284
2	$2ZnO3SiO_2$	0.39194
3	$3ZnO2SiO_2$	0.39438
4	$4ZnO1SiO_2$	0.40767
5	ZnO only	0.39060
6	SiO_2 only	0.39006
7	Steel	7.2

Table 2 showed the result of hardness for different samples by nanoindention test. The average hardness of the samples of different loading of nanoparticles is respectively 0.39284 GPa, 0.39194 GPa, 0.39194 GPa and 0.47067 GPa, which are all giving better hardness than sample without nanoparticles. By comparing sample 0 with 1-6 that containing nanoparticles, it can be found that nanoparticles has higher hardness. The reason is that, the nanoparticles was distributed uniformly into matrix (epoxy) and having good bonding process. Samples without nanoparticles showed lower hardness because higher porosity as shown in figure 2. Higher porosity will result in lower hardness. All these results are agreeing with the conclusions in Ref [5] and [6]. Small size of nanoparticles makes it beneficial to increase the performances of nanocoating [7]. Increase the amount of nanoparticles increasing the hardness. However too much of nanoparticles also decrease the hardness because aggregation [8]. The hardness of steel type S50C showed in figure 3 below.
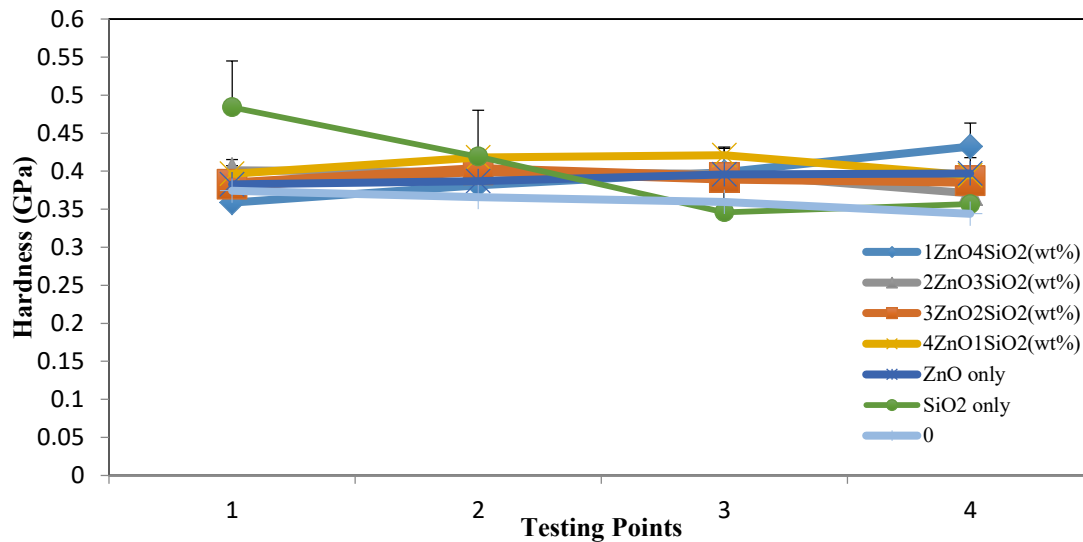
Figure 2. Hardness of nanocoatings by Nanoindentation test
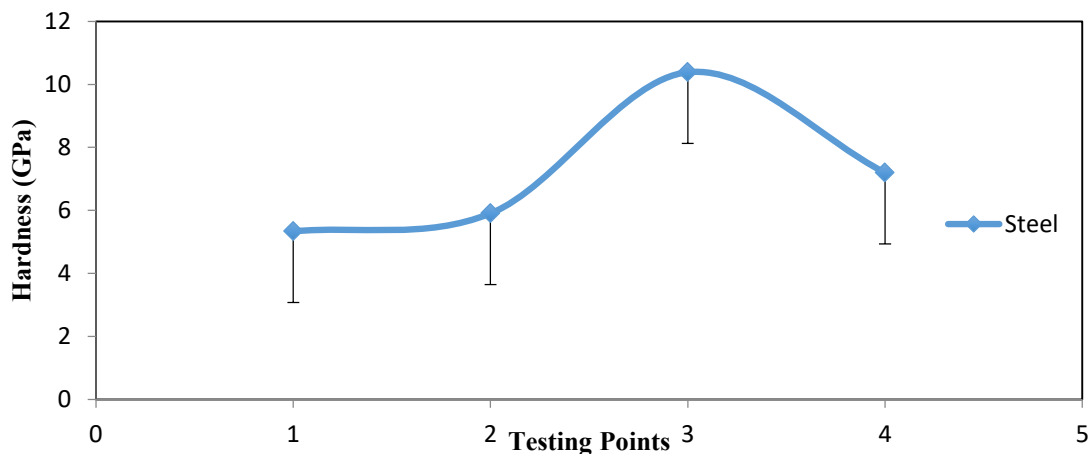
Figure 3. Hardness of Steel by Nanoindentation test

4. Conclusion

In summary, it can be demonstrate that 3wt% ZnO and 2wt% SiO$_2$ addition of nanoparticles into nanocoating was the best formulation since hardness and adhesion of nanocoating was good on carbon steel substrate. Incorporation of nanoparticles into coating increases the performances of coating.

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