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STUDY OF MECHANICAL PROPERTIES OF WOLLASTONITE FILLED EPOXY FUNCTIONALLY GRADED COMPOSITE

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ABSTRACT

Functionally graded materials (FGMs) have an incessant change in the composition over the thickness, which brings about a continuous difference in the properties. The capacity of the FGMs to perform in excess of one is differentiating capacities as an integral structure makes them an appealing material for aerospace applications. In this investigation wollastonite particles filled epoxy were studied. Particles were added with (0, 2, 4, 6 and 8 wt. %) to epoxy separately and together as functionally graded composite and the effects of the addition of wollastonite on the epoxy risen were investigated. Moreover, to improve surface performance, epoxy/stearamide coating layer had been applied to the outer surface with 800 μm thickness. The mechanical properties such as Impact, tensile and flexural strength, as well as, the surface properties (coefficient of friction, wear rate, and contact angle) had been studied. Scanning electron microscopes SEM were used to characterize the fracture surfaces. It is found that the fracture toughness of graded reinforced composite is higher than that of the unreinforced epoxy and non-graded reinforced composite, while the flexural modulus is found to be lower in the graded composites as compared to the unreinforced epoxy but it has a median value compare with non-graded composite. Tensile strength decreased in graded composite, while hardness increased with increasing fillers contents. The coefficient of friction was decreased with increasing the percentage of stearamide in the coating layer, the static contact angle increased linearly with increasing weight percentage of stearamide compare with the pure epoxy. The gradient showed clearly in scanning electron microscope.

Keywords: wollastonite, epoxy, functionally graded, mechanical properties.

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1. INTRODUCTION

Functionally graded material (FGM) is a novel kind of composite material that has a continuous change in structures through the thickness resulting gradual and incessant change in characteristics from the surface to surface. This helps to eliminate the stresses that are concentrated between the layers and the interface problem, which is the starting point of the failure resulting from the wide variation between the layers with a regular transition from surface to surface in laminate composite materials [1, 2].

FGM resolved the problem of different properties in the material as it contributed to the improvement of two or more contradictory properties in the same material [3] .

Nature always guides people to solve their problems and find answers to many questions when solving these problems. Human notes regular materials having inclination properties, for example, bone, teeth, wood, bamboo, human skin and the outside structure of arthropods, God made the teeth with a reviewed structure of properties with high protection from wear in the external layer in the internal layer will be flexibility since it needs to ingest the stun and protection from disappointment [4].

As of late, FGM has been utilized as a part of numerous applications, for example, electrical, photovoltaic, mechanical aerospace, medicinal, chemical and car applications. FGM performance depends on the distribution and arrangement of materials that are designed to meet the requirements of the part designed for it [5].

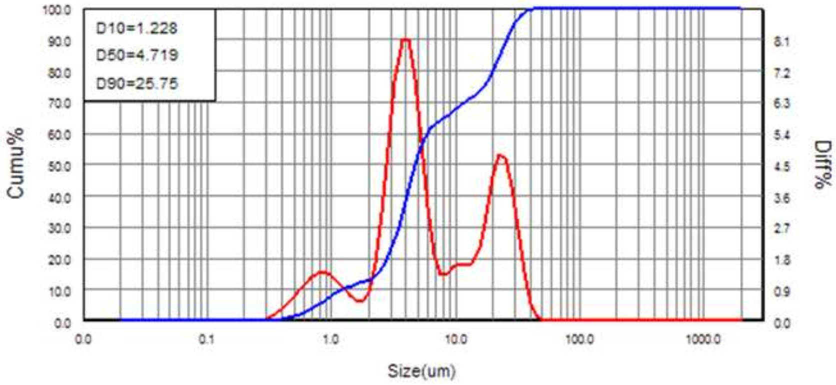
Matthew et.al, prepared functional graded composite material to improve mechanical behavior of crack by used (epoxy and alumina) in different rate (5-50%) [6]. Multi-layer of a composite material of epoxy and graphite was prepared by Stabik et.al with ratio (0, 5, 10 and 15%) from graphite to each layer to improve friction modulus [7]. Rihan and Abd-Elbary prepared functional graded from epoxy and silica in rate (0, 10, 15, and 20%) from silica to improve wear strength with increase the moment of silica [8]. Shoumya and Shorowordi used polyester and graded and non-graded Nano clay to study the mechanical behavior of each sample, they found that the graded composite improve modulus and strength [9].

The aim of the present work is to produce functionally graded composite materials from wollastonite with epoxy and evaluation by mechanical characterization and comparison between graded and non-graded composite.

2. EXPERIMENTAL PROCEDURE

2.1. Materials

A high-quality epoxy resin used as the matrix material (Bisphenol A (epichlorohydrin) oxirane [(c-12-14 alkyloxy) methyl]) and Hardener –amine (3-aminomethyl-3,5,5-tri methyl cyclo hexylamine) from Sika Co. Ltd. The density of cured epoxy resin about 1.14 gm/cm3. Wollastonit particles provided by Guangzhou billion peak chemical technology Co., Ltd. with no surface treatment were included as the strengthening fillers. The particles had Needles form with diameters distribution as shown in Fig. (1)



Diam um	Percent
0.100	0.00
0.200	0.00
0.500	1.36
1.000	8.02
2.000	12.83
5.000	53.38
10.000	67.40
20.000	80.18
45.000	99.91
75.000	100.00

Figure 1 Wollastonite particle size

2.2. Sample Preparation

The epoxy resin was mixed with different weight percentages of wollastonite (0, 2, 4, 6, and 8) using a mechanical stirrer for 30 minutes. The prepared mixture put in an oven under vacuum at 50 °C for 30 minutes to eliminate bubbles. Then add the hardener (with ratio 1:3) and manually mixed for 3-5 minutes, then the mixture was poured in a mold with dimensions (200 × 100 × 4) mm then leave for 24 hours at room temperature and curing the sample in the oven for four hours at 100 ° C.

For prepared the FGM by casting step-by-step method, was produced by the successive pouring of resin with several filler volume contents. In a gravity molding process, the mold was partially filled with the first layer of epoxy mixed with a specific volume content of wollastonite, and in a further step, the second layer of epoxy mixed with different volume content of wollastonite was poured on the partially solidified first layer, the layers were arranged from (0-8) wt. % from wollastonite. When the layers are complete, we put the sample at 100 ° C for four hours. The reinforced epoxy composite plate with wollastonite particles was cut into specimens with proper dimensions and shapes for testes.

2.3. Coating Preparation

To prepare anti-friction coating solutions, the epoxy resin was mixed with verity weight percentages of stearamide (0, 0.25, 0.5,1 and 2 %) and sheared by a magnetic stirrer for one hour and then curing agent was added to the resin followed by stirring for 5 min. Finally, FG substrates coated with a resultant solution with thickness (≈ 800 μm) using a Doctor Blade technique Fig. (2). All coated samples were cured at 100°C temperature for 3hours. The neat epoxy control samples were prepared in the same manner.

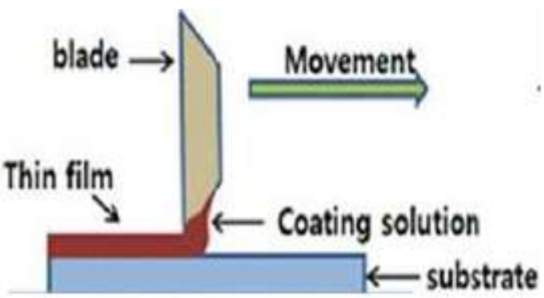


Figure 2 Doctor Blade method for coating [10].

2.4. Testing

A pendulum ram impact-testing machine utilizing rectangular samples (80*10*2.1) mm³, according to the ISO 179-1 [11], performed Un-notched Charpy impact tests; the distance between supported was 60 mm. Flexural properties were carry out in accordance with ISO 178 [12], using the instron universal testing machine. The sample sizes were (80 *10 *2.1) mm³ and the crosshead shift rate was keep at 2 mm/min. The load-deflection data was record at the same intermissions up to a point at which the specimen displays the first sign of failure. The space between the supports was 60 mm .Tensile properties were measure according to ASTM Standard Method D 638 [13], by employing a Universal Tensile Test machine (Bongshin model WDW-SE). The strain rate was 5 mm/min

Wear tests were carry out by using a pin-on-disc wear tester (Tribometer test device model MT/ MICROTEST system). The turn velocity of the disc was 70 rpm and the diameter of the wear pathway was 6 mm. The slipping speed between the pin and the rotating discs was 0.046 m/s. The slipping space was 28 m within the wear test period 600 s. The ecological condition in the testing research center was 35 ◦C.

Wear testing was do keeping in mind the end goal to quantify the friction coefficient and wear resistance of the different type of composites in different wear conditions. The Friction coefficient of the coated sample is gotten under the consistent sliding speed of 70 rpm at various connected normal load of 1– 15 N. This is acquired by separating the frictional power by the connected ordinary power [14]. The outcome for each sample average of four sample for all tests.

3. RESULTS AND DISCUSSION

Un-notched Charpy impact energy of the pure epoxy and wollastonite-epoxy composites are shown in Fig. (3). When a small amount of wollastonite particles adding, a reduction in the impact energy and fracture toughness was observed, but at high concentrations, an increase in the impact energy was observed and the maximum impact strength is found at the particle content of 8 wt. %. This may be because additions with low rates are insufficient to penetrate polymer chains in a compact manner, it becomes known as impurities, and the material is weakened. However, when the amount of wollastonite increases, the fracture toughness of the material is increased as the material becomes supportive of the polymer.

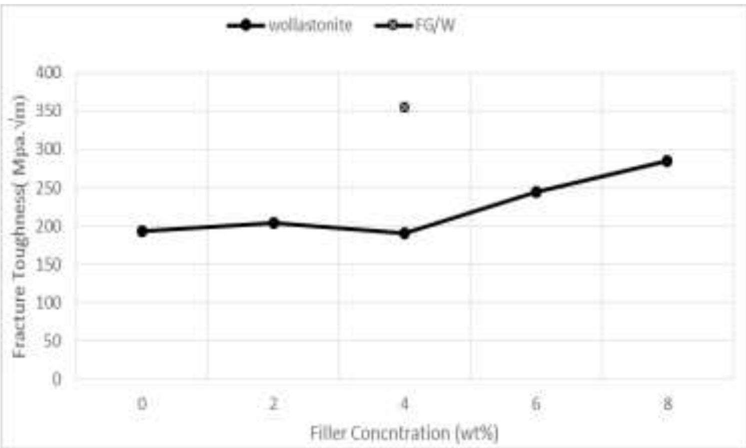


Figure 3 Fracture toughness as a function of wollastonite content

On the other hand, we can note that functionally graded composite have higher fracture toughness compare with other types of the composite at different concentration of wollastonite due to within functionally graded material the changed microstructural levels have changed purposes, and the overall functionally graded material accomplish the multi-structural position from their property gradation. By steadily changing the weight fraction of basic materials, their material properties display a flat and continual change from one surface to another, thus removing interface problems.

Fig. (4) Presents the data on the flexural properties of the pure epoxy and the wollastonite particles epoxy composites. The flexural modulus shows a straight lessening with the filler contented until 4 wt. % after that can be seen increasing in modulus value arrivals to 8 wt. % of wollastonite because of wollastonite particles display a constructive outcome on the flexural modulus.

The tensile modulus of pure epoxy, epoxy reinforced with non-graded and epoxy reinforced with graded are shown in **Fig. (**5). It is observed that the tensile modulus of pure epoxy decrease by about 40% with the addition of non-graded wollastonite. The reason behind the decline in strength of an epoxy with the addition of non-graded wollastonite may be attributed because of the agglomeration of particles and furthermore because of the inhomogeneous blend between agglomerated wollastonite particles and epoxy. However, an opposite result has been achieved for functionally graded composite, where it be seen the value of tensile modulus for functionally graded composite higher than all type of non-graded composite due to their material properties show a flat and continual change from one surface to another, thus removing interface problems

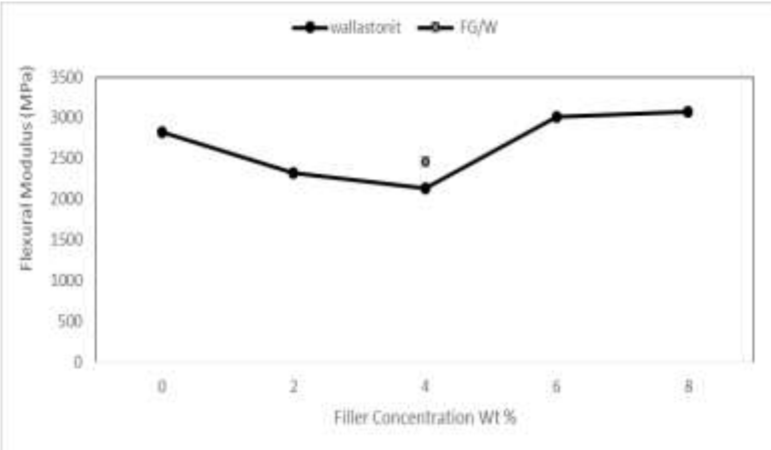


Figure 4 Flexural modulus as a function of wollastonite content

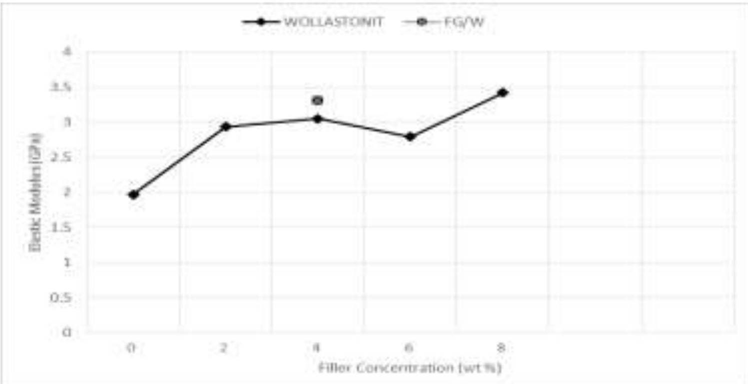


Figure 5 Tensile modulus as a function of wollastonite content

The micro hardness of pure epoxy and epoxy reinforced with non-graded wollastonite is presented in **Fig. (6)** At a different value of loads. From this figure, it is seen that the hardness of unreinforced epoxy is lower than their composite and, this is because the resistance to withstand indentation increase upon addition of wollastonite in the epoxy. On the other hand, can be seen the value of micro hardness increase with increasing the value of applied load due to increasing the reaction of material.

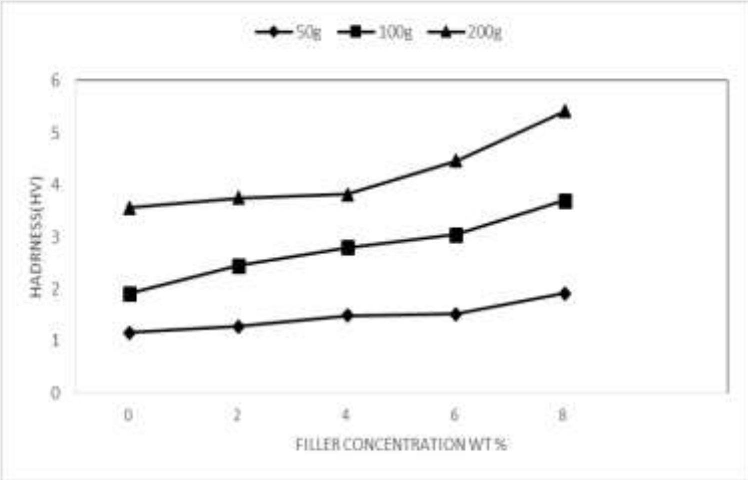


Figure 6 Effect wollastonite on Vickers hardness of epoxy/ wollastonite composites

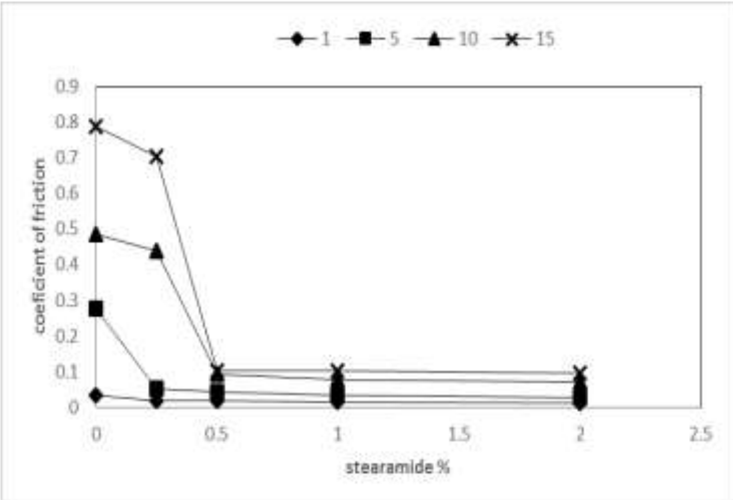


Figure 7 Relation between the coefficient of friction and stearamide percentage at different loads.

In general, as the useful normal load growths, the coefficient of friction growths. The friction coefficient was clearly reduced with increasing the percentage of stearamid in the coating layer due to the lubricating achievement of the stearamide. The friction coefficient values of composites in the early transitory state are higher than those in the stable state because the material adherence to the film decreases the friction in the stable state.

If we take the friction behavior under normal load 15N as an example, for pure coating surface the friction coefficient μ was 0.786, and after adding stearamide by a various percentages, the friction coefficient significantly decreased by 86.7% at 0.5 wt. % of stearamide and then reaches a constant value which indicated that there is a critical concentration for slipping agent must be taken into account. The lubrication is active only when the amide reaches complete coverage of the polymer surface. The lubricating up activity was caused by the migration of stearamide to the surface of the polymer with time and making a thin layer of amide on the coating surface. Fig. 8 records a change in the form of the wear with reverence to the useful load for changing weight percentage of stearamide.

In general, weight loss during wear test increases with increasing normal load, due to increasing the contact zone between polymer surface and counter surface. During wear testing, the pure epoxy carried on in a weak conduct and cracking were framed opposite to the slipping way. Therefore, material waves were formed and wear rubbish was created. With the incorporation of stearamide into the epoxy matrix, the weight reduction was diminished and the spread of the cracks hooked on the epoxy matrix was slowed down to a certain degree by the stearamide on or close to the surface cover. Besides, a slipping agent in a polymer matrix would diminish the wear rate in case of the shear stress less than a critical value both of these could add to the diminishment of the wear rate of the epoxy matrix. For any given filler content, said 0.5 wt.%, the slipping agent were migrated to the surface and make a thin layer on the epoxy surface which can diminish the interfacial shear stress between polymer surface and counter face, and consequently the better the wear resistance obtainable by the stearamide.

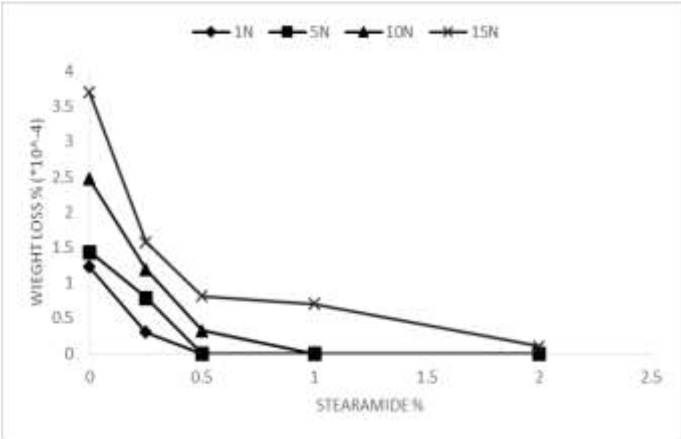


Figure 8 Relation between weight loss and stearamide percentage at different loads.

Fig. 9 shows the measured water contact angles on the coating surface. Mean calculated contact angles are plotted versus weight percentages of stearamide. As a comparing with the pure epoxy, the static contact angle increased linearly with increasing weight percentage of stearamide in the epoxy coating layer. The contact angles start at hydrophilic values 76.7° on the pure epoxy layer. For coating layer contained 2% stearamide, contact angle increased from 76.7° for the pure epoxy to 118.5°, which confirm that the slipping agent immigrated to the epoxy surface.

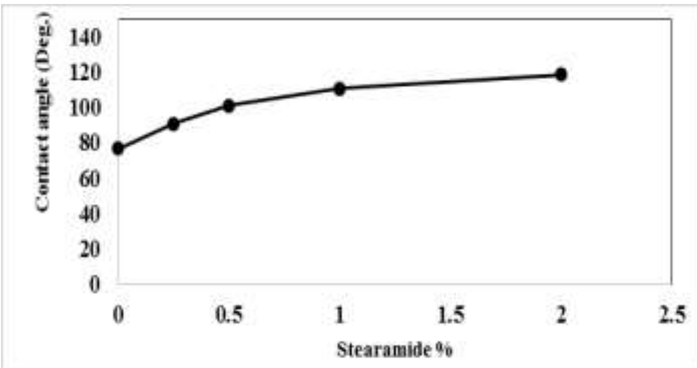


Figure 9 Relation between contact angle and stearamide percentage.

Fig 10 show the Visual investigations on the fracture surfaces of particulate filled epoxy resins by scanning electron microscope technique and can be often reflected complete facts about the distribution of the wollastonite in the epoxy matrix.

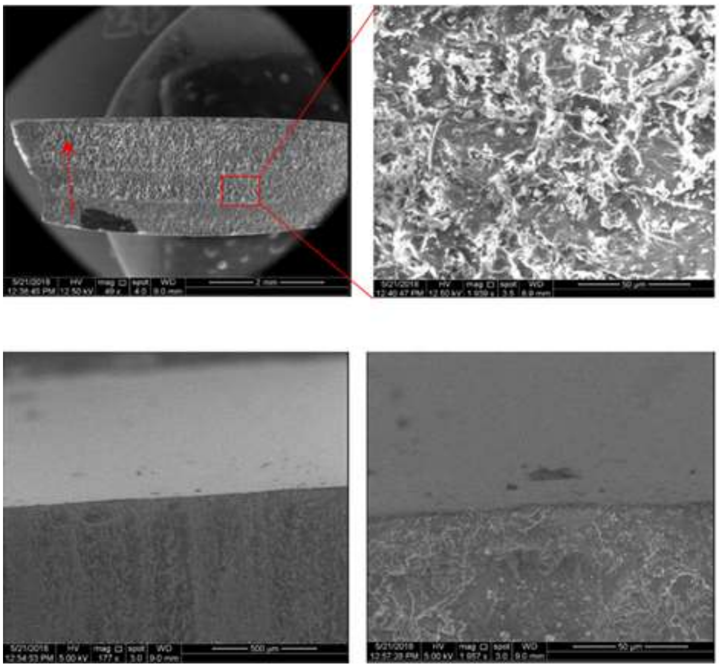


Figure 10 Scan electron microscope for fracture surface

The images showed the gradient in the padding concentration within the matrix where the concentrations change from 0 to 2.5% and the homogeneous distribution of the wollastonite in the epoxy matrix compared with pure epoxy.

4. CONCLUSION

A comparative study for wollastonite particles reinforced epoxy functionally graded composites (FGCs) have been prepared using gravity casting.The particles were added at (0, 2, 4, 6 and 8 wt. %) to the epoxy separately and together as functionally graded composite and epoxy/stearamide coating layer had been applied to the outer surface with 800 μm thickness. Impact, tensile and flexural strength, in addition to surface properties and scanning electron microscope were studied for the fracture surfaces.

A reduction in the impact energy and fracture toughness was observed at a small amount of wollastonite particles adding. At high concentrations, an increase in the impact energy was observed and the maximum impact strength is bringing into being at the particle contented of 8 wt %. Functionally graded composite have higher fracture toughness compare with other types of the composite at different concentration of wollastonite. The flexural modulus displays a linear decrease with the filler contented until 4 wt. % after that can be seen increasing in modulus value arrivals to 8 wt. % of wollastonite. The tensile modulus of pure epoxy decrease by about 40% with the addition of non-graded wollastonite. For functionally graded composite, the value of tensile modulus higher than all type of non-graded composite due to their material properties exhibition a flat and incessant change from one surface to another.

The value of micro hardness increase with increasing the value of applied load due to increasing the reaction of material and the hardness of unreinforced epoxy is lower than their composite.

The friction coefficient was clearly reduced with increasing the percentage of stearamide in the coating layer. The lubrication is active only when the amide succeeds complete coverage of the polymer surface. The lubricating exploit was affected by the immigration of stearamide to the surface of the polymer with time and creating a thin layer of amide on the coating surface. With the incorporation of stearamide into the epoxy matrix, the weight loss was decreased and the spread of the cracks into the epoxy matrix was hindered to a certain degree by the stearamide on or close to the surface layer.

The static contact angle increased linearly with increasing weight percentage of stearamide in the epoxy coating layer.

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