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The Effect of Aggressive Biological Materials on a Painted Automotive Body Surface Roughness

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Abstract: There are different aggressive biological materials which may potentially deposit on a painted automotive body surface during its service life, causing possible local damage, loss of appearance and loss of protective aspects of the system. In this study, the effect of two types of aggressive biological materials on a painted automotive body surface, i.e., natural bird droppings and raw eggs were studied and subsequently explained in more detail. Furthermore, two different testing conditions approaches including in-door and out-door were utilized in order to investigate the surface roughness, R_a, and also to study the behavior of biologically degraded automotive body surface at nano-level scale. The effects of these biological materials on a painted automotive body surface and its appearance were investigated by Atomic Force Microscopy (AFM) and a stylus-based inductive gauge (Taly-surf®, from Taylor Hobson, Inc.), having electromagnetic control of the contact force. Engaged vertically on the top of the specimens, the force could be set much lower than the weight. Results showed that natural bird droppings and raw eggs have a dramatic effect on the appearance and surface roughness of a painted automotive surface body. It was also found that the degradation which occurred due to the natural bird droppings was more severe than that of the samples exposed to raw eggs.

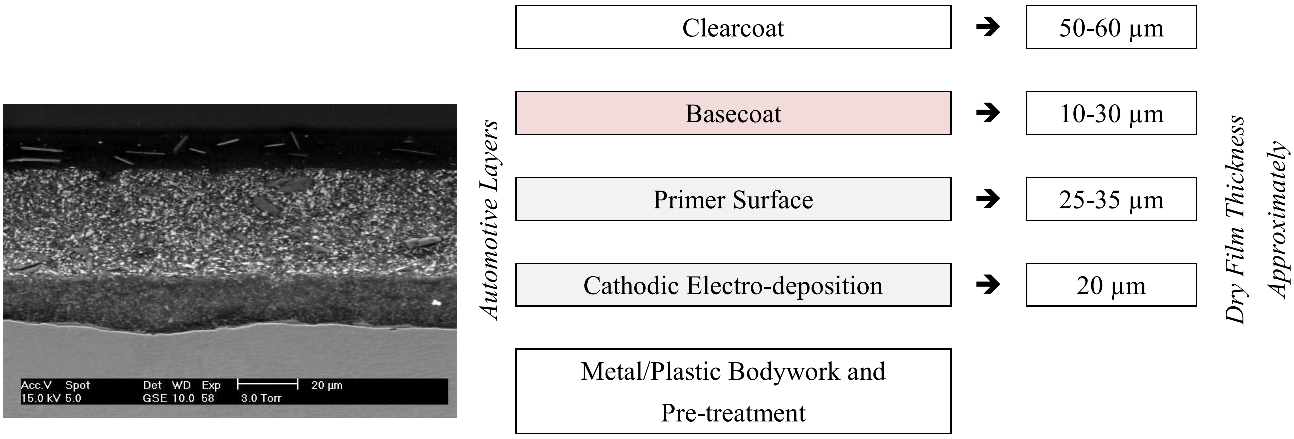
Keywords: Biological, Automotive, Bird Droppings, Raw Eggs, Roughness

1. Introduction

Automotive paints are more complex and precisely engineered than is often appreciated. They often consist of many different layers or 'parts', each chosen to give a precise function in order to provide the desired balance of properties [1]. Appearance of a painted automotive body surface is certainly highly significant for the consumer. This not only seems to be a detrimental property, its retention during service life is of great importance [2]. Primarily, the basic objectives of the painting process are to protect and decorate functions of the motor vehicle body, in which its purpose is to enhance or change an object's appearance, to change its colour or level of gloss or to draw attention to a particular region on the object [1, 3]. However, just as important, there is a need for protection from any environmental conditions (e.g., mechanical, weathering, biological) in terms of degradation of automotive coatings or to lengthen their lifetime [4]. Since the introduction of automotive coatings systems to luxury car lines in the early 1980s, their use has increased dramatically to the point where they are used on all cars nowadays, as protective prescriptions for items as diverse as airplanes, automotives, bridges, houses and machinery [5]. An automotive coatings system contains different layers or 'parts', each of which plays a key role in its overall performance. These layers or 'parts' typically consist of phosphating conversion pre-treatment, followed by cathodic electro-deposited coating to provide anti-corrosive properties (together with the pre-treatment layer of the car body). These are then coated by a primer surface to enhance mechanical properties. After that, the base-coat layer intended to provide colour and effect is also of high importance in supporting the shape of the car body, and finally, the clear-coat layer for appearance and protection [6]. Fig. 1 shows a typical automotive coating system with approximated dry film thickness and an image of a typical cross-section through a painted panel. Considering all variables, it is inevitable that the clear-coat chemical, the mechanics and appearance can be significantly influenced [7]. However, in different parts of the world, there is often variation in product technology in practical terms as regards topcoat (base-coat and clear-coat), and this can have a significant influence on paint performance, specification and particular details of the process [1].

Moreover, there are different parameters which may affect the clear-coat surface chemistry and can directly influence the anti-corrosive performance of this layer during their exposure to outdoor factors [8]. These mainly include weathering environments (e.g., UV radiation from sunlight, water and humidity, acid rain, hot-cold shocks) [9-11] and biological materials (e.g., bird droppings, raw eggs, tree gum, insect bodies) [2, 4, 12-17]. In response to this, a variety of exposure methods and test protocols have been developed to anticipate the long-term weathering behavior of coating failure and predict performance [10-12, 15, 18-23].

In the literature, published data relating to the impact of external factors on the degradation process of top coatings have been major topics during recent years. Perhaps surprisingly, when seeking ways to precisely investigate the impact of surface roughness, R_a, at nano-level scale on a painted automotive body surface during exposure to aggressive biological materials (e.g., bird droppings and raw eggs), there appears to be no authoritative public data available. Therefore, the present work aims to study two aggressive biological materials, i.e., natural bird droppings and raw eggs, under two different testing conditions approaches including in-door and out-door conditions with the intention of investigating the surface roughness, R_a, on a painted automotive body surface on a small scale.



(a) (b)

Figure 1. *(a) a typical cross-section through a painted panel and (b) paint layers on vehicles with approximated dry film thickness, adapted from [4]*

1.1. Biological Materials

Throughout history, various types of biological materials have been responsible for degradation of a painted automotive body surface. The most important of these are bird droppings, raw eggs, tree gum and insect bodies [7, 12, 23, 24]. Biological materials have various chemical compositions that can affect coatings' degradation differently [4, 6, 16]. Among the biological materials, the influence of natural bird droppings and raw eggs will be explained in more details, as they are the most important factors which affect the chemical, mechanical and visual performance of automotive coatings. It must be emphasized that no attempt is made to be comprehensive and just a few specific areas in natural bird droppings and raw eggs are discussed.

1.2. Natural Bird Droppings

In general, birds have no bladder; they do not store liquid waste separately from solid waste. All of their waste is mixed together in an organ called the 'cloaca', (the cloaca is the terminal chamber of the gastrointestinal and urogenital systems, opening at the vent). Solid waste from the intestines is mixed with concentrated uric acid ($C_5H_4N_4O_3$) from the kidneys and everything is eliminated together. The uric acid levels in natural bird droppings is relatively high, reaching pH of somewhere between 3.0 and 4.5, which is quite acidic. So, in terms of a painted automotive body surface, these extra Hydrogen (H^+) ions found in the uric acid of bird droppings will react with the hydrocarbons of the body surface and slowly break down the clear-coat of the body surface in the order of a few nano-meter levels. Thus, natural bird droppings contain uric acid, a chemical that is corrosive enough to quickly eat through a coating of wax or paint sealant and begin to etch.

It is worth mentioning here that it also contains different types of amylase, lipase and protease enzymes, which can hydrolyze 'ester' and 'ether' linkages of the clear-coat resin which leads to the formation of soluble products and subsequently to release from the coating, resulting in the formation of cracks and holes in the film surface [12].

- *Amylase enzyme:* (pH ≈ 7, neutral) breaks down starch/carbohydrates into simple sugars.
- *Lipase enzyme:* (pH ≈ 8, slightly alkaline) breaks down lipids (fat) into glycerol and fatty acids.
- *Protease enzyme:* (pH ≈ 2, highly acidic) breaks down protein into amino acids or into smaller protein molecules by breaking the peptide bond joining them.

Enzymes are protein molecules that speed up some chemical reactions and begin others. Without enzyme catalysts, the biochemical actions required for each body function would not occur fast enough and the body would cease to live. Most enzymes are much larger than the substrate they act upon, and only a small portion of the enzyme (around 3.0 to 4.5 amino acids) is directly involved in the hydrolytic catalysis [7, 12, 13, 15, 16]. It was also illustrated that an enzymes activity is affected by temperature, chemical environment and the substrate composition [25-27]. It was found that natural bird droppings decrease the appearance parameters of the clear-coat, i.e., gloss, distinctness of image and colour value hence negatively affecting the aesthetic properties of the coating system [23]. Indeed, the mechanism of this type of degradation seems quite controversial. Whatever the mechanism of this failure, chemical, and/or physical, one can expect that the biological resistance of automotive coating depends on different parameters such as the chemical composition of the biological substances, chemistry of the curd coating, as well as on the physical and/or chemical properties of the coating system itself, and more importantly, on the synergistic effect of environmental factors combined with these aggressive chemicals [12].

Fig. 2 shows the image of pigeon and natural bird droppings on a painted automotive body surface (colour: red car).

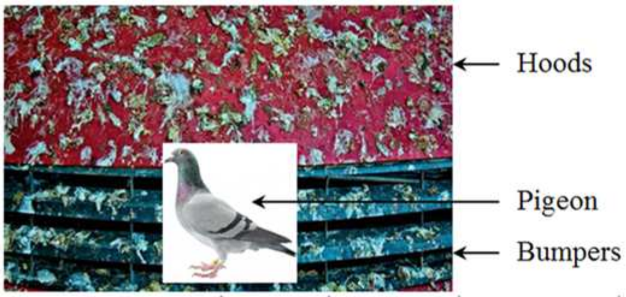


Figure 2. *Image of pigeon and natural bird dropping on a painted automotive body surface*

1.3. Raw Eggs

In addition to natural bird droppings, raw eggs (as biological material) also play a key role in rendering the coating to gradually diminish its appearance leading to catastrophic failure.

Weight and composition of hen eggs vary, and is dependent on species, feed, age, habitat, and several other factors. Among all the factors, poultry feed significantly influences the chemical and physical composition of hen eggs. A hen egg is composed of three major parts: white, yolk, and shell. According to the published data (% of total weight), the whole egg consists of (9 - 11% shell), (60 - 63% white) and (28 - 29% yolk) and the average weight is 57g [28, 29].

Additionally, eggs are good source of several important nutrients including protein, total fat, monounsaturated fatty acids, polyunsaturated fatty acids, cholesterol, choline, folate, iron, calcium, phosphorus, selenium, zinc and vitamins A, B2, B6, B12, D, E and K. They are also a good source of the antioxidant carotenoids, lutein and zeaxanthin [30].

Stevani and his colleagues in [22], studied the influence of dragon-fly eggs on an acrylic melamine automotive clear-coat. They found that the hydrogen peroxide released during hardening of eggs, oxidizes the cysteine and cysteine residues present in the egg protein, leading to the formation of sulfinic and sulfonic acids. The acids produced then catalyze the hydrolytic degradation.

It seems that dragon-fly eggs show the same damaging mechanism of biological materials as natural bird droppings and pancreatin (simulated natural bird droppings) on clear-coat. Both dragon-fly eggs and natural bird droppings may catalyze the hydrolysis reaction of clear-coat in hot-humid conditions but with different mechanisms. Dragon-fly eggs produce an acidic pH whereas natural bird droppings catalyze the hydrolytic reaction of clear-coat using their enzymatic structure [12, 22, 31]. Fig. 3 shows the image of raw eggs on a painted automotive body surface and the general structure of the egg.

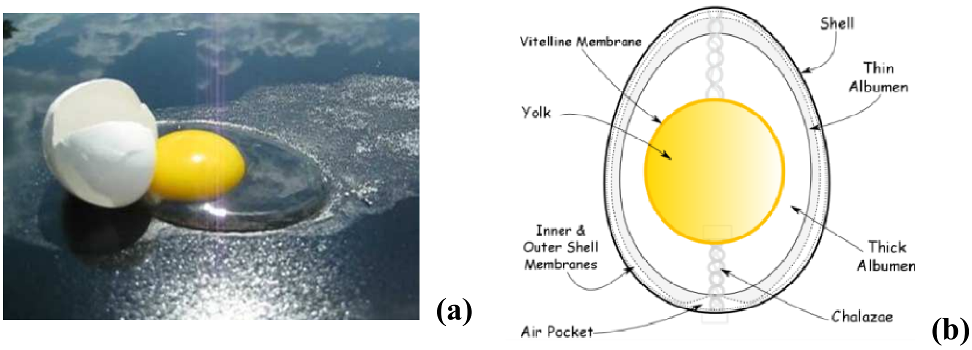


Figure 3. *Image of (a) raw eggs on a painted automotive body surface and (b) general structure of egg*

2. Experimental

2.1. Biological Materials Selection

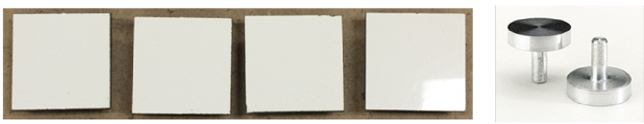
Various types of biological materials are responsible for degradation of a painted automotive body surface. However, the two biological substances utilized were natural bird droppings and raw eggs. The natural bird droppings were collected from a pigeon and the raw egg dropping were purchased from the farm. All biological materials involved in this experiment were collected from a single city namely Makkah (as the feed significantly influences the chemical and physical composition of both pigeon and hen egg). Table 1 shows the specification of biological materials used in this study. Ramezanzadeh and his co-workers in [12] used pancreatin (which is a mixture of several digestive enzymes produced by the exocrine cells of the pancreas) as the synthetic equivalent of natural bird droppings. On the other hand, although the natural bird droppings contain different impurities and effects, all the chemical composition of the natural bird droppings was used in order to stimulate the real live data and investigate the impact of the surface roughness on a painted automotive body surface on a small scale.

Table 1. *Specification of biological materials used in this study (approximate pH number)*

Biological Materials	Specifications			
	pH	**Bird Name**	**State**	**Colour**
Natural Bird Droppings	4.0	Pigeon	Liquid	Gray
Raw Eggs	8.0	Hen	Liquid	White/Yellow

2.2. Sample Preparations

More than 300 samples (a white painted automotive body surface, from the Toyota Company, KSA, model 2013) were used in this study with identical dimensions of length of 30 × 30 × 0.85 mm. A Waterjet machine (from TecnoCut waterjet cutting systems) was used to cut the front of the painted automotive body surface into identical dimensions. Each sample was mounted onto an aluminum sample holder (of a standard commercial and inexpensive nature) using the commercial adhesive. This was accomplished by dispensing an equal amount from two tubes onto a clean disposable surface and mixing this thoroughly for 45 seconds and then using it for 4 minutes. To eliminate any misalignment between the samples and the surface of the aluminum sample holder, the adhesive was added at the surrounding end of the sample holder. This is vital in order to avoid error in the measurement being introduced by misalignment of the measurement systems. Fig. 4 shows the image of the sample to be tested and the aluminum sample holder.



(a) **(b)**

Figure 4. *Image of (a) sample to be tested and (b) aluminum sample holder*

It is of the utmost significance before starting the experiments to clean the specimens of any surface contaminants, such as dust, grease, or any other soluble organic particles so that there will be no adverse effect on the results. To achieve this, all specimens were ultrasonically cleaned in two five minute steps: (1) water with detergent to remove dust and oil, and (2) distilled water to remove detergent, and this was followed by warm air drying. After cleaning, the specimens were stored for 24 hours in the same environment (in-door and out-door) that would be used for the testing to allow the sample surface condition to equilibrate with the environment. The procedure described above was judged to be adequate at this stage.

2.3. Testing Procedures

In this work, the process of degradation on a painted automotive body surface takes place under two different conditions during the first 24 hours of the impact as follows:

- *In-door conditions:* testing took place in an artificial atmosphere, with an ambient temperature of 20±1^{o}C and a relative humidity of greater than 40±5% RH.
- *Out-door conditions:* testing took place in weathering environments (e.g., UV radiation of sunlight, humidity, hot-cold out-door shocks, acid rain) which impose different kinds of degradations on a painted automotive body surface during the experiment.

According to these testing conditions, all samples were covered by the natural bird droppings and raw egg. The surface profile of a painted automotive body surface was quantitatively analyzed in order to determine the statistical standard parameter of average roughness, R_a, by using Taly-surf® (from Taylor Hobson Precision, Inc) which delivers 0.8 nm resolution over 12.5 mm seamless measuring range and includes 0.125 µm horizontal data spacing. A nominal 2 µm stylus was used with a normal load of 0.7 mN and selectable traverse speed down to 0.5 mm s^{-1} and which conforms to British Standards see Fig. 5. Surface roughness errors were calculated from the standard deviation of the absolute values of height deviation (absolute values). The traces were auto-leveled to a linear least-squares straight line and then filtered with a standard 0.8 mm cut-off. The surface parameters were selected according to the recommendations in the literature and also with respect to the data processing facilities available [32-36].

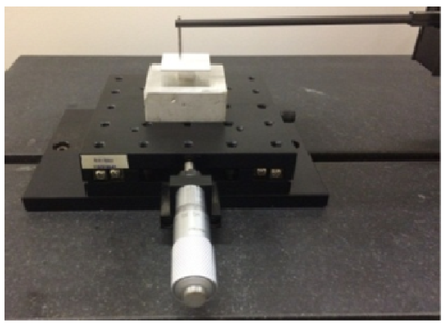


Figure 5. *Image of Taly-surf® and x-y stages for mounting the sample holder and specimen.*

Every test condition was repeated at least three times at different "*new*" locations on a painted automotive body surface in order to ensure reproducibility of the results. The new location was ±100 µm from the previous one. This approach should have avoided any alteration of the counterbody surface, e.g., due to wear, which might occur during the test and affect the measurements in the following tests. All experiments were performed with a typical "*ball-on-flat*" arrangement applying a linear sliding contact at constant velocity over a specific distance. Tests were performed by using single scan mode (forwards motion). The profiler had a scan length of 10 mm, which is close to the size of a human fingertip.

2.4. Calibration Procedure

Standard calibration ball radius D = 22.0161 mm, 112/1844, Serial No. 639-506-B (from Taylor Hobson Precision, Ltd.) was used to calibrate the test-rig. For convenience, ten calibration trials have been carried out. This is adequate as these trials are predominantly about relative behavior; design interpretation to other systems is always vulnerable to variations in terms of materials and dimensions. Calibration showed the cantilever was a linear spring ($R^2 > 0.99$), under operating and environmental conditions typical for this type of device, with absolute uncertainties of <1% of reading and realizable measurement resolution down to at worst 50 nm. Fig. 6 shows the set-up of the standard calibration ball and the systematic diagram of the ball and a nominal 2 µm stylus with a normal load of 0.7 mN and selectable traverse speed down to 0.5 mm s^{-1}.

This method of calibration ensures that the gauge travels through (and therefore, is calibrated over) most of its range.

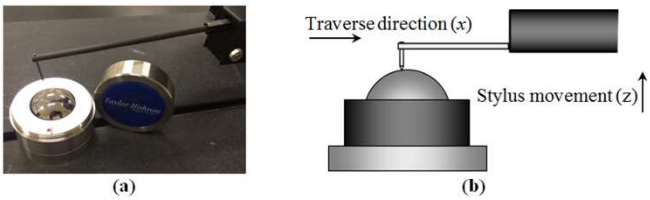


Figure 6. *(a) image of standard calibration ball radius D = 22.0161 mm, 112/1844, Serial No. 639-506-B (b) ball with nominal 2 µm stylus*

For further investigation of the degradation process AFM microscope Park NX10 were utilized to investigate the effect of biological materials on the surface morphology of the automotive body surface.

3. Results and Discussions

As has been previously mentioned, the present work aims to study the effect of two types of aggressive biological materials on a painted automotive body surface, i.e., natural bird droppings and raw eggs under two different conditions (out-door and in-door) with time. In all, over 300 separate experiments (not all successful) and samples were tested. Surface roughness, R_a, has been extensively used to determine the total average roughness and the degraded net (before and after the attack) during 24 hrs. Fig. 7 illustrates an example of a painted automotive body surface roughness before and after the attack of biological materials (i.e., natural bird droppings and raw eggs), which also indicated that even the smoothest surfaces are rough on the atomic scale and that contact only occurs at the tips of asperity peaks. It is worth mentioning here that mathematically, R_a, is the arithmetic average value of the profile departure from the mean line of the surface, within a sampling length.

Besides the conventional roughness parameters, R_a, the statistical parameters R_{sk} (skewness) and R_{ku} (kurtosis) were determined. R_{ku} is a measure of the randomness of profile heights. A perfectly random surface has a value of 3. The further the value is from 3, the more repetitive the surface is. Spiked surfaces exhibit high value, whereas bumpy surfaces possess lower value. From the R_{sk} value, a conclusion can be drawn about the symmetry of the profile about the mean line. Negative R_{sk} values point to a predominance of valleys, while positive values correspond to a peaked surface.

The surface analysis revealed that a varying predominance of valley surface features indicated by the negative R_{sk} values was measured on these samples. Additionally, it was observed that the structures of these samples have more repetitive features ($R_{ku} > 3$).

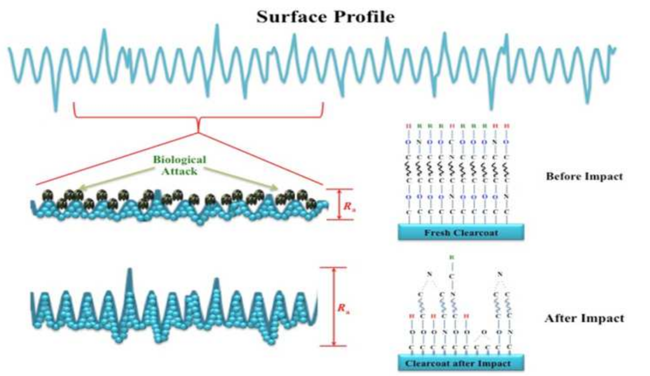


Figure 7. *A typical example of a painted automotive body surface roughness before and after the attack of biological materials*

3.1. Effect of Natural Bird Droppings on a Painted Automotive Body Surface

A painted automotive body surface was exposed to natural bird droppings for both (in-door and out-door) conditions. The effect of the natural bird droppings on a painted automotive body surface before and after exposure is shown in Fig. 8(a) and 9(a). In real conditions, almost always, a clearcoat layer of body car surface experiences both biological and natural environmental processes (sunlight and humidity) conditions before and after the attack of the natural bird droppings. These figures show that the surface of the clearcoat before any exposure is smooth. However, both environmental and biological attacks roughened the surface. Also, it is evident that this roughening phenomenon becomes more severe when both environmental and biological conditions are introduced simultaneously. The author in [37] mentioned that the UV portion of sunlight causes degradation, because it has energy content sufficient to break chemical bounds.

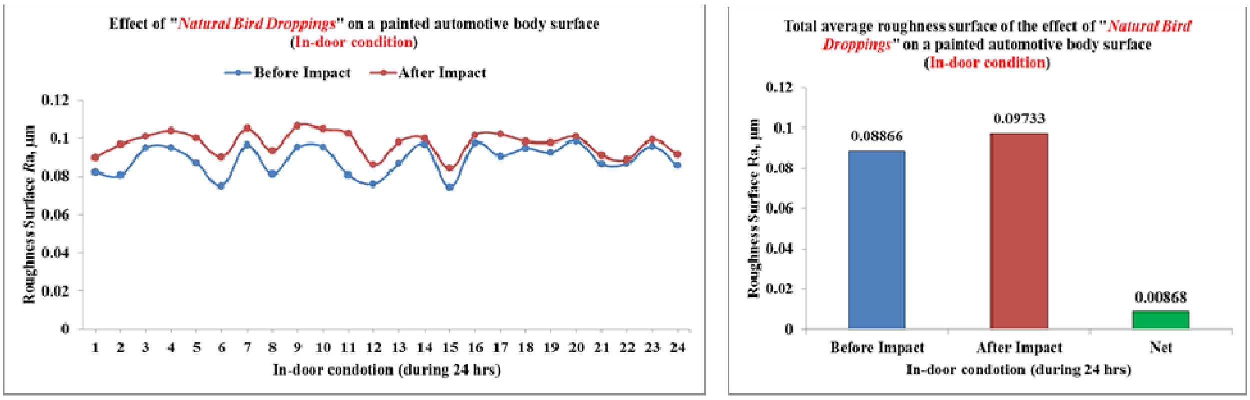


Figure 8. (a) effect of natural bird droppings on a painted automotive body surface during 24 hrs (b) total average roughness with degraded net (In-door condition)

As can be seen from Fig. 8(b) and 9(b), the degraded net of the total average roughness surface of the effect of natural bird droppings on a painted automotive body surface in (out-door condition), $R_a \approx 12.7$ nm, were higher than those obtained in identical testing (in-door condition), $R_a \approx 8.6$ nm. Back to Fig. 1(b), which represents the typical cross-section through a painted panel, the dry film thickness of the first automotive layer of the clearcoat is approximately 50 – 60 µm. So, it is clearly during the first 24 hrs of the impact of the biological material (i.e., natural bird droppings) for both conditions (in-door and out-door), the degradation was only in the clearcoat layer of the automotive body car surface to a depth of 12.7 nm and 8.6 nm, respectively. As a result, the appearance and the protection layer of the body car surface degraded by a few nano-levels of a total micro-level.

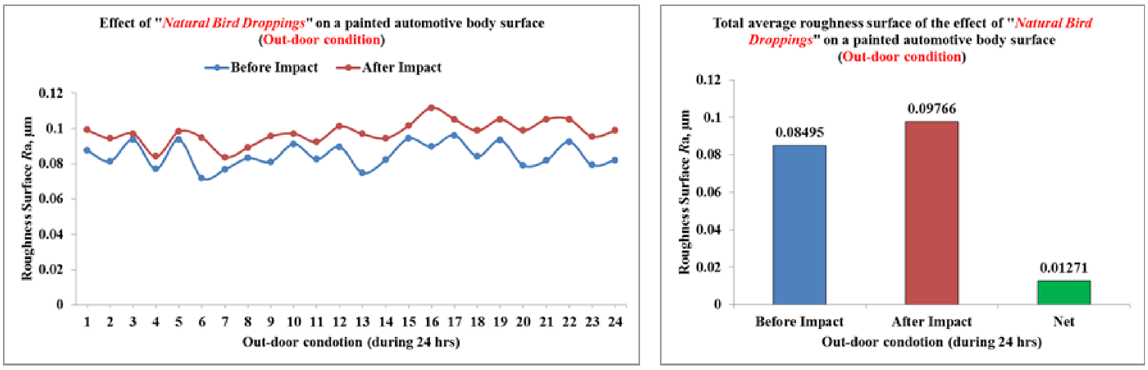


Figure 9. (a) effect of natural bird droppings on a painted automotive body surface during 24 hrs (b) total average roughness with degraded net (Out-door condition)

3.2. Effect of Raw Eggs on a Painted Automotive Body Surface

It is clear from Fig. 10(a) and 11(a), that the total average roughness curves, R_a, were affected in the presence of raw eggs on the samples at different times and conditions. Each sample represents a specific time, this is why the average roughness curve, R_a, fluctuated during 24 hrs before and after impact. However, the total average roughness of the sample at each hour during 24 hrs increased after the impact of the biological material (i.e., raw eggs) on all samples depending on the atomic structure of the surface and leading to the degradation on a painted automotive body surface.

As can be seen from Fig. 10(b) and 11(b), the degraded net of the total average roughness surface of the effect of raw eggs on a painted automotive body surface in (out-door condition), $R_a \approx 8.5$ nm, were approximately twice as high as those obtained in identical testing (in-door condition), $R_a \approx 5.3$ nm. It was felt that this might be due to the effect of the environmental parameters such as UV radiation of sunlight, humidity and hot-cold out-door shocks, which may accelerate the process of the degradation on a painted automotive body car surface during the same period of experiment (24 hrs).

Refer to Fig. 1(b), which represents the typical cross-section through a painted panel, the dry film thickness of the first automotive layer of the clearcoat is approximately 50 – 60 µm. So, it is clearly during the first 24 hrs of the impact of the biological material (i.e., raw eggs) for both conditions (in-door and out-door), the degradation was only in the clearcoat layer of the automotive body car surface by 5.3 nm and 8.5 nm, respectively. As a result, the appearance and the protection layer of the car body surface degraded by a few nano-levels of a total micro-level. This relationship between the dry film thickness and average total profile roughness can indeed be used to monitor the total average degradation of the effect of the aggressive biological materials on a painted automotive body surface.

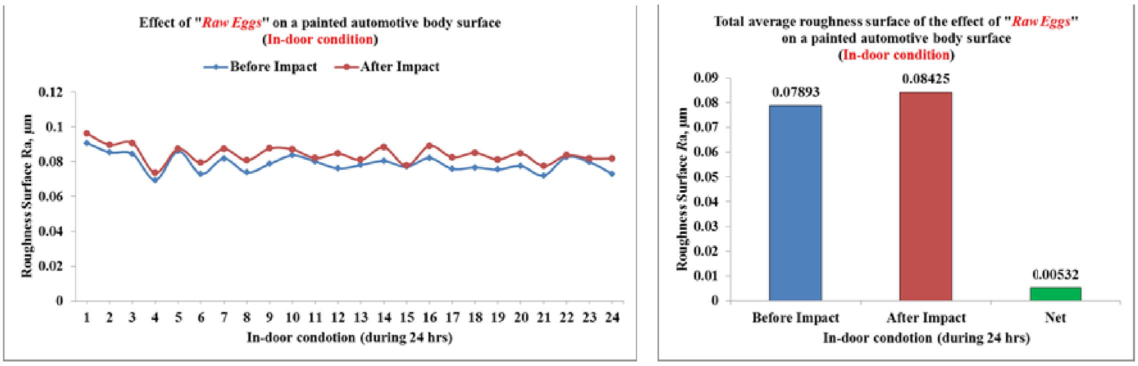


Figure 10. *(a) effect of raw eggs on a painted automotive body surface during 24 hrs (b) total average roughness with degraded net (In-door condition)*

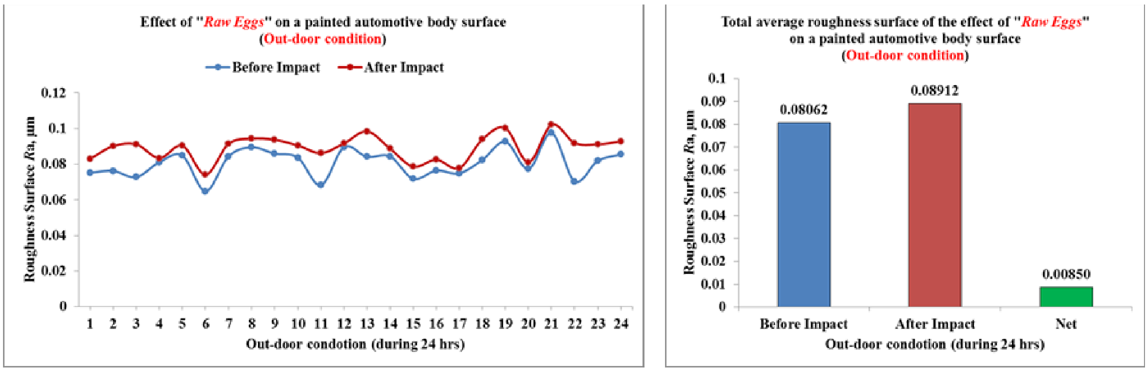


Figure 11. *(a) effect of raw eggs on a painted automotive body surface during 24 hrs (b) total average roughness with degraded net (Out-door condition)*

3.3. Visual Evaluation

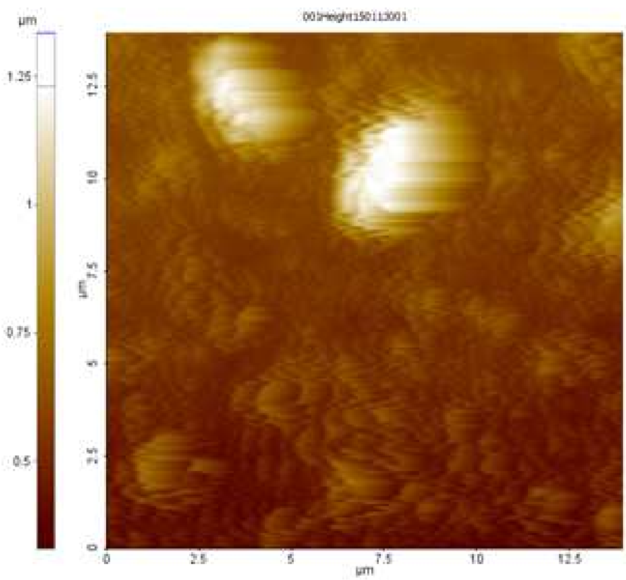


Figure 12. *typical 2-D AFM micrographics painted automotive body surface before impact*

Visual performance of an automotive body surface can be regarded as the main objective to follow its behavior up on exposure to outdoor conditions. To study the effect of biological material (i.e., raw eggs) on a painted automotive body surface, Atomic Force Microscopic (AFM) technique was utilized. Fig. 12 shows the typical 2-D AFM micrographics of sample before impact. Also, Fig. 13 shows a typical 2-D AFM micrographics on painted automotive body surface after 1 hrs impact of raw eggs (out-door condition). Fig. 14 shows typical 2-D AFM micrographics on painted automotive body surface after 24 hrs impact of raw eggs (out-door condition).

The comparison between the AFM micrographics painted automotive body surface before impact Fig. 12 with the other samples Fig. 13 and Fig.14 shows that the biologically exposed samples have been roughened and this may possibly be attributed to biological degradation. More severe degradations were discerned for a sample exposed to 24 hrs impacts of raw eggs (out-door condition). However, no noticeable surface defects can be observed for the blank (painted automotive body surface before impact).

As can be seen from Fig. 13 and 14, although the surfaces have been exposed to varying short/long times to biological effect, this substance has etched the surfaces of both samples (after 1 hrs impact of raw eggs (out-door condition) and after 24 hrs impact of raw eggs (out-door condition)) catastrophically. It can be observed that the scales at which the effect of biological materials can be clearly distinguished are quite different in Figs. 13 and Figs 14. The observations made in these two figures, which depict the presence of cracks and roughened areas, as well as the formation of blisters and white stains on samples may explain the morphology changes observed in samples as a result of etching made by biological materials. These images may confirm that chemical reactions have occurred on the surface, leading to dissolved and etched areas. Gerbig and his colleagues in [38], originate the same results.

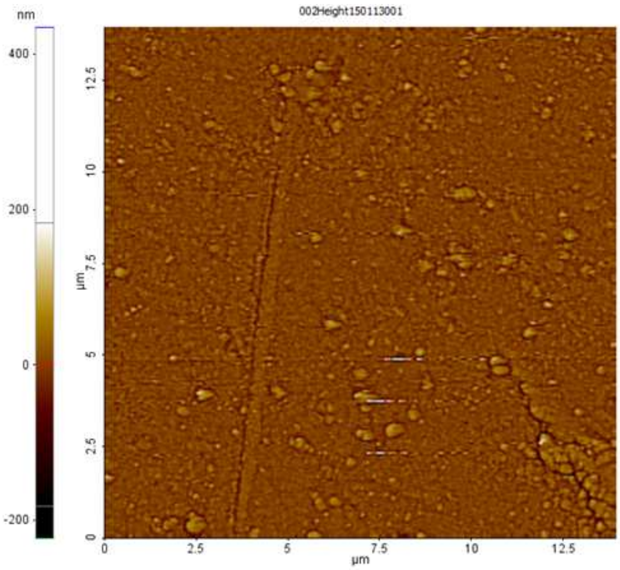


Figure 13. *typical 2-D AFM micrographics on painted automotive body surface after 1 hrs impact of raw eggs (out-door condition)*

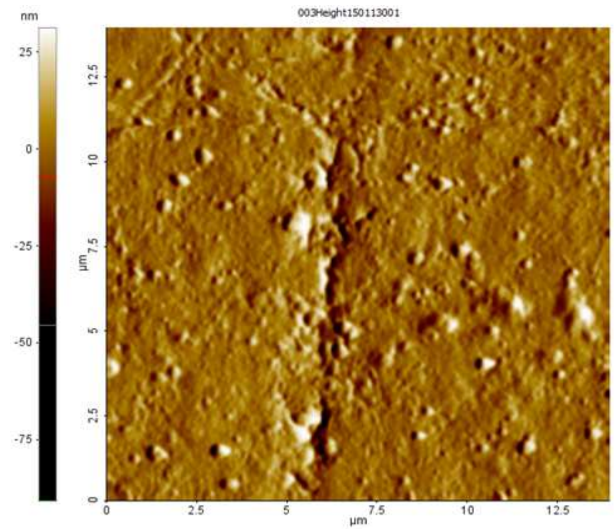


Figure 14. *typical 2-D AFM micrographics on painted automotive body surface after 24 hrs impact of raw eggs (out-door condition)*

4. Concluding Remarks

The effect of two types of aggressive biological materials on a painted automotive body surface, i.e., natural bird droppings and raw eggs were studied and further explained in more detail, which has a significant influence on economics and safety, especially for metals. Taking into consideration the weathering environments (e.g., UV radiation of sunlight, humidity, hot-cold out-door shocks, acid rain), results showed that mechanical, chemical and physical properties might be alert as a result of damage to the appearance and the surface roughness of a painted automotive body surface. According to the results of the present study, both mechanical and chemical properties of the clear-coat are important parameters influencing the level of clear-coat resistance to natural bird droppings and raw eggs.

The general conclusions obtained are shown below:

- In all cases, $R_{a\ \text{(bird droppings, out-door)}}$, represents the rougher structured samples and indeed the more degraded samples by $R_a \approx 12.7$ nm.
- There was no significant variation of degradation in any of the tests between natural bird droppings (in-door condition) and raw eggs (out-door condition), where, $R_{a\ \text{(bird droppings, in-door)}} = 8.6 \text{ nm} \approx R_{a\ \text{(raw eggs, out-door)}} = 8.5$ nm.
- $R_{a\ \text{(raw eggs, in-door)}}$, represents the smoothest structured samples and indeed the less degraded samples by $R_a \approx 5.3$ nm.
- As expected, R_a, fluctuated in nano-level during the first 24 hrs before and after the attack of specifically natural bird droppings and raw eggs on a painted automotive body surface due to surface structure, distribution of asperities, manufacturing process or environmental factors.
- As a function of time, it was found that the material structure defect formation before and after impact, results in conventional surface roughness, R_a, effects: $R_{a\ \text{(bird droppings, out-door)}} > R_{a\ \text{(bird droppings, in-door)}} > R_{a\ \text{(raw eggs, out-door)}} > R_{a\ \text{(raw eggs, in-door)}}$.

In conclusion, we believe that the new methodology that was used in this paper to measure the degradation on a painted automotive body surface has enormous potential in the field of micromechanics and nanotechnology.

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