JKAU: Eng. Sci., **vol. 15 no. 2**, pp. 81-96 (2004 A.D./1425 A.H.)

Investigating the Abrasive Wear Behaviour of Locally Used Automotive Paint

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ABSTRACT. The objective of this research is to investigate the abrasive wear behaviour of polymer base automotive paint, which is locally used for steel painting. Research has been conducted under dry, water lubricated, and water-soap lubricated conditions. The effects of applied load, sliding distance, abrader surface roughness, and paint drying time on the abrasive wear volume and abrasive wear rate were investigated under controlled environment of 23°C temperature and 40% humidity. The examined paint was used directly on steel substrate with no primer. Preliminary results show that wear volume increases with increasing applied load, sliding distance and abrader roughness. However, results also show decreasing wear volume with increasing drying time up to 50 hr. Beyond this value, time seems to have little effects on abrasive wear behaviour. This argument is valid for all four conditions of tests. As for abrasive wear rate, results show decreasing abrasive wear rate with applied load sliding distance, abrader surface roughness, and drying time. Results clearly indicate that the presence of water significantly increases the wear volume and wear rate. Furthermore, the addition of soap to water increases the wear volume and rate to even higher levels.

KEYWORDS: tribology of paints, abrasive wear of paints, car paints and polymers.

1. Introduction

Automotive paints are exposed to various environmental factors that affect their service lives. Modern automotive finish paints are highly engineered multilayer viscoelastic coatings. Expectations for paint finish range from cosmetic appeal to functional performance. Customers concerns from a cosmetic perspective are akin to photo-oxidation, effect of acid rain, gasoline spills, and car wash chemical environments [1].

Such expectations raise the general need for an improved understanding of the factors (such as paint properties, structure of painting system and location, and substrate materials) controlling the durability of the paint coatings used in automotive applications. It has been claimed that appropriate testing and test methods can play more important part in coating technology than resins and paint formulations [2]. However, automotive industry currently lacks quantitative tests for assessing the durability of paint systems under conditions of both impact and abrasive wear.

In spite of that, earlier work on tribology of paints in general and automotive paints in particular, distinguished three most significant mechanisms of wear: (a) Erosive mechanism, where paint films are subjected to wear and / or they are damaged by impact of water, particles and solid objects such as stones (called stone chipping) [3-8]; (b) Adhesive mechanism, where paint films are subjected to adhesion to the counterpart surface due to friction, hence resulting in a cohesion and delamination of paint layers [9-12]; and (c) Abrasive mechanism, where paint films are subjected to abrasion by various abraders such as fabrics and abrasive paper under dry and lubricated conditions [13].

2. Experimental Details

2.1 Abrasion Test Methods

BS 3900-E15 and ISO 7784-2 are alternative names for the same method which is intended for determining the resistance to abrasion of dry film of paint. Another similar method of paint testing is the ASTM D4060. In the first method, the dried film of paint is abraded under specified conditions with abrader. The author used this method in conducting all the abrasion tests with some necessary modifications. The resistance to abrasion is defined as the loss in paint mass. Details of the modified test method will be given under the experimental procedure.

2.2 Specimens and Preparation

Steel panels of (100 x 50 x 2.5 mm) dimensions were used as substrates for the abraded painted specimens. They were cut to size from commercial steel slabs supplied by the Attia Co., Jeddah, Saudi Arabia.

The surface of each panel was carefully flattened and ground on machine to ensure quality flatness, then it was prepared to the required roughness using abrasive paper with specified grade, then covered by a thin film of the paint under investigation, and let to dry in an open environment of (60 °C) maximum temperature. No primer was used on steel panels. The drying time was varied within the range of (12 – 72) hours at (12) hours interval.

2.3 Abrader

Different grades of abrasive papers were used as abraders (counterparts) to the paint layers of specimens. The grades were varied within the range (CW200 2C – CW1200 2C). These are waterproof silicon carbide, elecrtrocoated, manufactured and supplied by SABCO of Korea. The abrader was firmly and flatly mounted on a stationary horizontal flat supporting solid surface of the testing rig.

2.4 Conditions of Tests

The tests were conducted under:

1. Dry condition where no lubricant was used at the area of contact between painted specimen and abrader.
2. Lubricated condition by immersion: the whole experiment system, specimen and abrader, was immersed into a bath of liquid lubricant, and the test run inside. Two lubricants were used (a) tap water, and (b) tap water plus soap solution formed by mixing 1% liquid soap with 99% tap water.
3. Lubricated condition by flowing stream: a continuous stream of tap of solution of water and soap flooded the area of contact.

2.5 Wear calculation

Abraded wear volume for each test was obtained from the differences in specimen weights before and after the run, and the dry density of the paint. Wear rate was then calculated using the Archard equation [14]:

$$V = k\,F\,S \qquad \Rightarrow \qquad k = V / FS \tag{1}$$

where V is the wear volume, F is normal applied load, S the sliding distance, and k is the specific wear rate.

2.6 Wear machine

A simple low speed reciprocating abrasive wear testing machine was employed in the course of this work to provide the relative sliding motion between the moving specimens and stationary abrader. The configuration of test set-up is shown in Fig. 1.

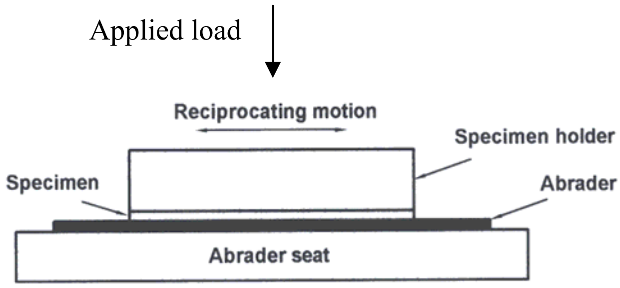

Fig. 1: Schematic diagram for test configuration.

One constant low sliding speed of 0.2 m/s was used over all experiments. This would significantly help in keeping the temperature rise at the area of contact due to friction at its lowest level, hence eliminating the unwanted thermal effects.

2.7 Balance

A precision electrical balance type (Toledo – AB104) manufactured and supplied by Mettler of Denmark was used in this research to derive the material losses of the specimen, hence evaluating the wear volume for each run. The balance accuracy was ± 0.1 mg as indicated by manufacturer and checked by the author.

2.8 Microscopy

An optical microscope type Ferox, 051594 manufactured and supplied by CETI of Belgium was also employed in this research work. It was mainly used to examine the area of contact on the paint film abrader surface, monitoring any loss of debris from the abrading surface, which usually causes three body wear.

3. Experimental methodology and procedure

Steps of experimental procedure were devised and strictly followed during the course of experiments. To avoid any spurious or unwanted results, all non - related parameters such as sliding speed, laboratory temperature and humidity were kept at preselected constant values. For accuracy purposes, each test was repeated at least three times. The average value of wear volume, and hence wear rate, were derived.

3.1 procedure steps for dry condition

3.1.1 *Load effect*

Tests were conducted using abrasive paper grade (CW600-2C) as abrader. The abrader was firmly mounted onto a horizontal flat solid surface. The sliding distance, sliding speed and drying time were kept at constant values of (10 m), (0.2 m/s) and (48 hours) respectively. The normally applied load was varied in the range (5-30 N) in an increment of (5 N) at a time. The steps of the test procedure were as follows:

1- Fresh abrasive paper grade (CW600-2C) was mounted on the horizontal flat support of the machine; then abrading surface was cleaned from any loose debris by soft brush.
2- The paint specimen was washed by distilled water and left to dry; then it was weighed and the weight was recorded.
3- The specimen was seated in place and firmly held by the specimen holder. Then the whole system of holder and specimen weas carefully lowered on the counterpart to establish the contact.
4- The load was applied on the top of specimen holder as shown in Fig. 1.
5- The machine was started, and a mechanical counter was used to count the strokes of the reciprocating motion on the specimen.
6- At the end of the run, the machine was stopped; the specimen removed and cleaned from any loose debris and/or worn paint, then weighed again and the value was tabulated.
7- New identical fresh specimen and abrader were used on restarting the test.

3.1.2 *Sliding distance effect*

The same steps were followed here. However, the applied load, abrader roughness, and drying time were all kept at constant values of (15 N), (CW600-2C), and (48 hours), respectively, whereas the sliding distance was varied in the range of (2.5 – 15 m), at an interval of (2.5 m) at a time.

3.1.3 *Abrader roughness effect*

Here also the same steps were followed. However, the applied load, sliding distance, and drying time were all kept at constant values of (15 N), (10 m), and (48 hours), respectively. Abrasive papers of grades were varied within the range of (CW200 2C – CW1200 2C), for abrasion of the paint layers of examined specimens. It may be pointed out that the greater the grade numbers, the smaller the grit size of sand paper. That is to say paper of grade number (CW1200-2C) has the finest grit size whereas number (CW200-2C) has the largest.

3.1.4 ***Paint drying time effect***

The same above steps were followed. However, the applied load, sliding distance, and abrader roughness grade were all kept at constant values of (15 N), (10 m) and (CW600-2C) respectively. The drying time of painted specimens was varied within the range of (12-72 hr), at an interval of (12 hr) at a time.

3.1.5 ***Procedure steps for lubricated conditions***

The same steps of dry conditions were also followed for all lubricated conditions. Tests were conducted as follows:

1- The specimen and abrader were immersed into a bath of lubricant during the run.
2- The specimen and abrader were subjected to a flowing stream of lubricant during the run.

4. Results and discussions

4.1 Applied load

Figure 2 shows the increasing abrasive wear volume with increasing normally applied load under all conditions of tests. This is expected, and can be explained by the simple theory of wear which suggest that wear volume is directly proportional to applied load, and inversely to the hardness of the material.

Comparison of all four curves of test conditions indicates that the presense of water at the area of contact significantly increases the wear volume of the paint. Furthermore, the addition of soap to water causes more increase in the wear volume, and the use of a stream of lubricant increases the wear volume even higher. This may be explained as follows: (a) poor lubricity of water; (b) the formation of paint transfer film on the abrader surface of dry tests curve lubricate the area of contact, hence keeping the increase in wear volume at low level. However, the presence of water significantly reduces this film, hence significantly increasing the wear volume; (c) the addition of soap to water helps even more in reducing this film, causing more increase in wear volume; (d) exposing the area of contact to a stream of water washes away all wear films and debris, and significantly raises the wear volume, see photo 1 to photo 4.

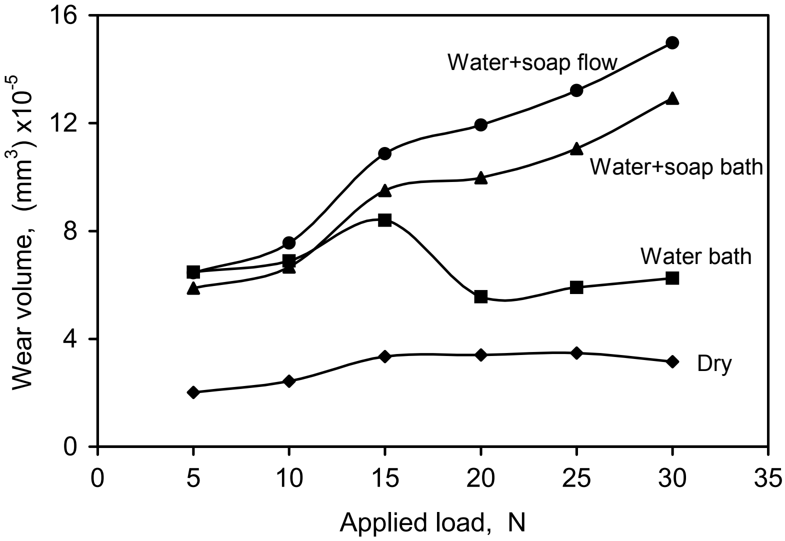

Fig. 2: Variation of paint wear volume with applied load under dry and lubricated conditions.

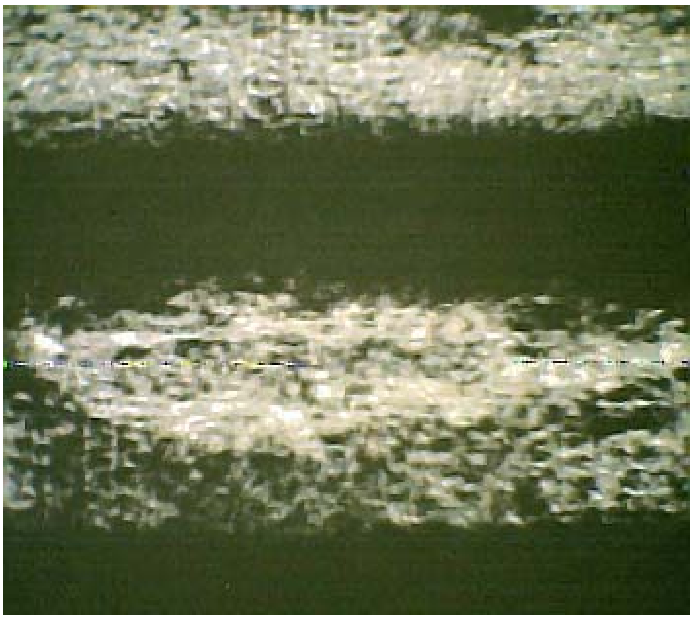

Photo 1: Paint transfer film - dry abrasion.

Photo 2: Paint transfer film – with water.

Photo 3: Paint transfer film in 1 % soap solution.

Photo 4: Paint transfer film in 1 % soap solution stream.

Figure 3 shows the decreasing specific abrasive wear rate with increasing normally applied load under all four conditions of tests. This also is expected since the curvature of wear volume is non-linear. Reasons for this behavior are the same as those indicated in the last paragraph for wear volume.

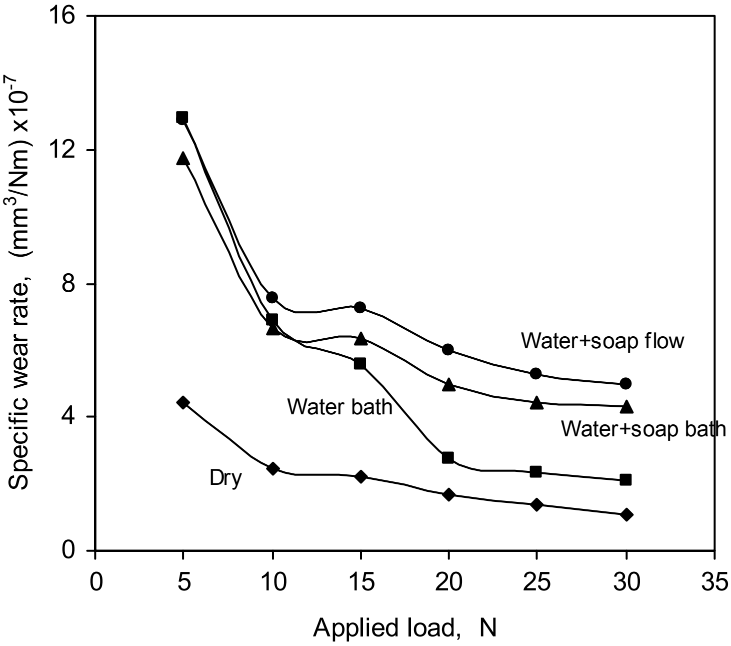

Fig. 3: Variation of paint specific wear rate with applied load under dry and lubricated conditions.

4.2 Sliding Distance

Figure 4 shows the increasing abrasive wear volume with increasing sliding distance under all conditions of tests. This is expected, and can be explained by the simple theory of wear which suggest that wear volume is directly proportional to sliding distance, and inversely to the hardness of the material. It also suggests that when two contacting materials are in relative motion to each other, the harder material always scratches the softer one.

Comparison of all four curves of test conditions indicates that the presence of water at the area of contact significantly increases the wear volume of the paint. Furthermore, the addition of soap to water causes more increase in the wear volume, and the use of stream lubricant increase the wear volume even higher. This may be explained by the same interpretation used earlier.

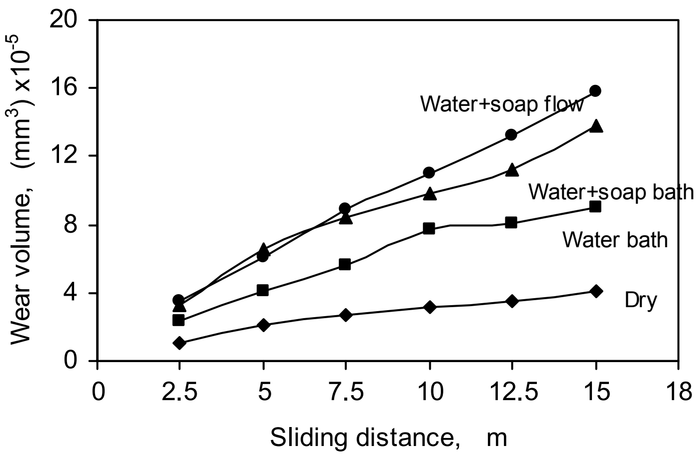

Fig. 4: Variation of paint wear volume with sliding distance under dry and lubricated conditions.

Figure 5 illustrates decreasing specific abrasive wear rate with increasing sliding distance under all conditions of tests. This also is expected for the same interpretation mentioned earlier.

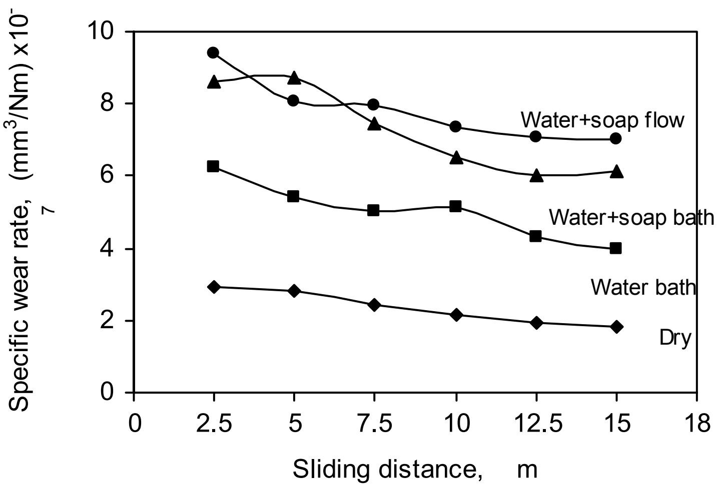

Fig. 5: Variation of paint specific wear rate with sliding distance under dry and lubricated conditions.

4.3 Abrader Surface Roughness

Figure 6 shows the increasing abrasive wear volume with increasing abrasive paper roughness under all conditions of tests. This behaviour is explained by early tribological findings. In addition, the effect of surface roughness is well establish by researchers, i.e., the rougher the abrader surface the greater the penetration into paint, and hence the greater wear volume.

Figure 7 shows the decreasing specific abrasive wear rate with increasing the roughness of abrading surface. This goes well along with the classical concepts of tribology.

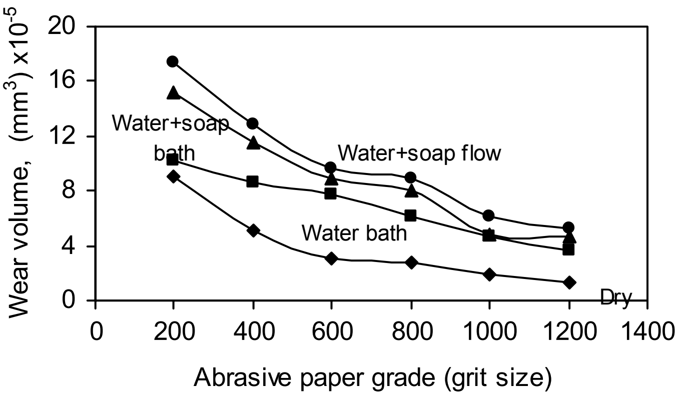

Fig. 6: Variation of paint wear volume with abrasive paper grade under dry and lubricated conditions.

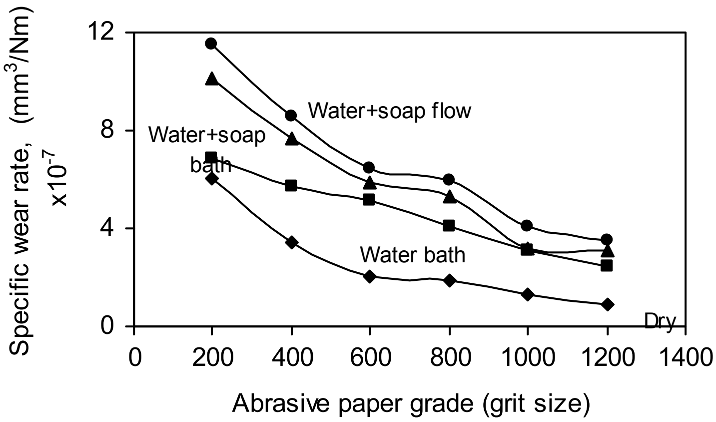

Fig. 7: Variation of paint specific wear rate with abrasive paper grade under dry and lubricated conditions.

4.4 Drying Time

Figure 8 shows the variation of abrasive wear volume with the drying time of paint under all conditions of tests. It indicates the decreasing wear volume with increasing drying time up to (48 h). Beyond this value time seems to have little effect on wear behavior. This can also be explained by the simple theory of wear which suggest that the wear volume inversely proportional to its hardness. The longer the drying time the stronger and harder the paint layer, hence the lower wear volume. However, the figure also shows that paint reaches its full hardness and strength in about (50 h) drying time.

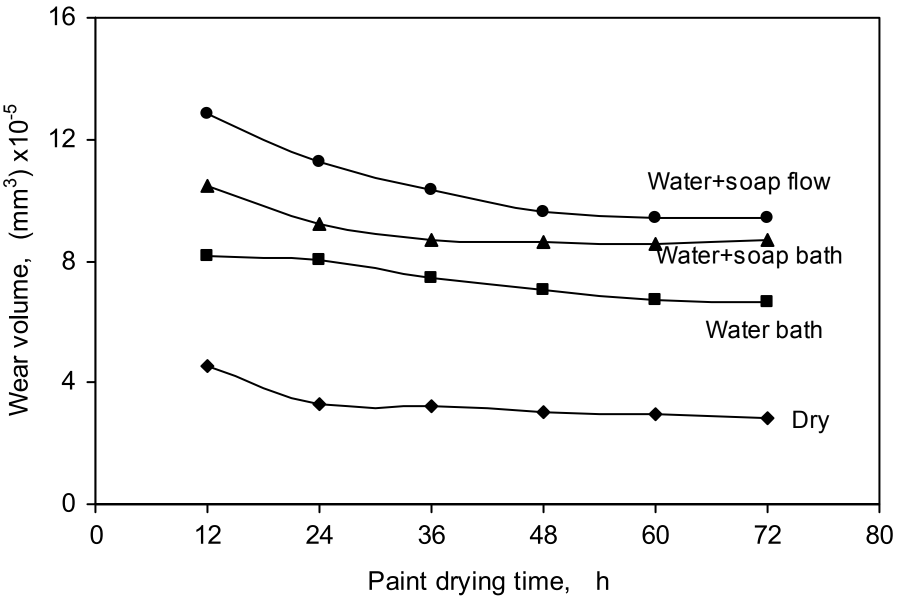

Fig. 8: Variation of paint wear volume with drying time under dry and lubricated conditions.

As for wear volume, Fig. 9 shows decreasing specific abrasive wear rate with increasing drying time up to (50 h). Beyond this value time seems to have little effect on wear rate.

Results of Figs. 1 and 2 show that the (50 hr) drying time seems to be the optimum time for paint to gain its full strength and hardness. However, more experiments are still conducted by the author to clarify this result.

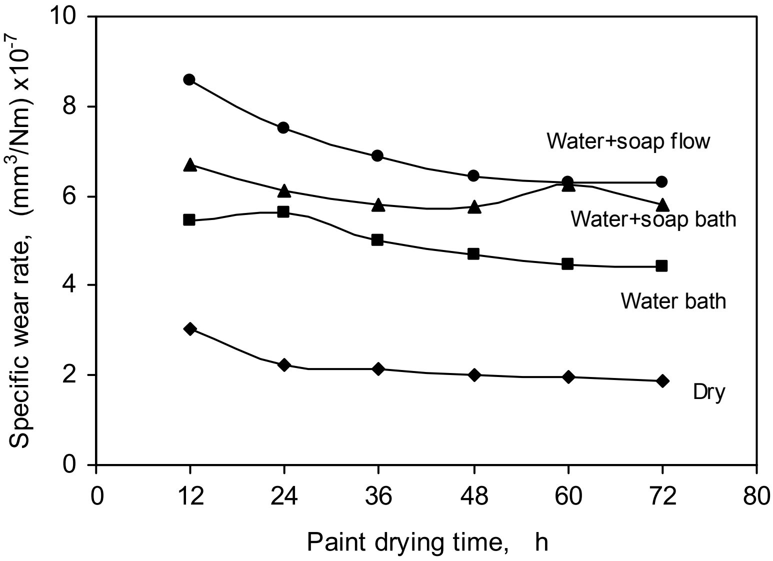

Fig. 9: Variation of paint specific wear rate with drying time under dry and lubricated conditions.

For comparison purposes, the abrasive wear properties of this (50 h) drying time are given in the following table. The wear volume and specific wear rate for all conditions of tests are tabulated in Table 1.

Table 1: Wear volume and specific wear rate.

Wear ratio of test conditions calculated relative to the "water-soap flow" condition				
Parameter	Condition s of tests			
	Dry	Water bath	Water soap bath	Water soap flow
Wear volume	31.5 %	73 %	89.34 %	100 %
Wear rate	31.5 %	73 %	89.34 %	100 %

The table shows that the flowing of water-soap emulsion at through the area of contact could triple the wear volume, hence specific wear rate.

5. Conclusions

Abrasive wear volume of the investigated paint increases with increasing applied load, sliding distance, abrader surface roughness, and paint drying time under all conditions of tests. The wear rate decreases with increasing applied load, sliding distance, abrader surface roughness, and paint drying time under all conditions of tests. The presence of water at the area of contact significantly increases the wear volume and specific

wear rate of paint. The addition of soap to water increases the wear volume and specific wear rate of paint to higher levels than water alone. The flow of water through the area of contact washes away all worn paint debris preventing adhesion to abrader surface, hence increasing the wear volume and wear rate to higher levels than immersion in bath. Full paint strength and hardness is reached in about (50 hr.) of drying time. Beyond this value, time seems to have little effect on wear volume and wear rate.

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بحث سلوك تآكل دهان المركبات - المستخدم محلياً - بآلية الحت

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المستخلص: يهدف هذا البحث لدراسة سلوك تآكل دهان المركبات (المستخدم محلياً في دهان الفولاذ) بآلية الحت. ولقد أُجريت الدراسة في الحالات الجافة، المزيتة بالماء، والمزيتة بالماء والصابون. وقد تمت في هذه البحث دراسة تأثير أربعة متغيرات على حجم ومعدل ناتج التآكل وهي: الحمل المطبق، مسافة الانزلاق، خشونة سطح عنصر الحت، وزمن تجفيف الدهان، وذلك في وسط ثابت الحرارة عند (23 °C) ورطوبة (40 %)، كما تم دهن عينات الفولاذ مباشرة بدون دهان أساس. وقد بينت التجارب أن حجم التآكل يزداد بزيادة الحمل المطبق، ومسافة الانزلاق، وخشونة سطح عنصر الحت. كما بينت هذه التجارب أن حجم التآكل يتناقص مع زيادة زمن تجفيف الدهان حتى (50 hr)، ثم بعد هذه القيمة يقل تأثير للزمن على حجم التآكل. وهذا لجميع أنواع التجارب التي تم إجراؤها. أما فيما يتعلق بمعدل التآكل فلقد بينت التجارب أنه يتناقص مع زيادة الحمل المطبق، ومسافة الانزلاق، وخشونة سطح عنصر الحت، وزمن التجفيف، كما بينت التجارب بوضوح أن وجود الماء يزيد بشكل كبير كلا من حجم ومعدل التآكل، كما أن إضافة الصابون إلى الماء يزيد حجم التآكل ومعدله لمستويات أعلى.