

THE EFFECT OF NITRIDE AND TITANIUM CARBONITRIDE COATINGS ON WEARING OF COLD FORMING TOOLS

CÁSSIO AURÉLIO SUSKI, CARLOS AUGUSTO SILVA DE OLIVEIRA

Departamento de Engenharia Mecânica – Universidade Federal de Santa Catarina
Florianópolis – SC Brasil
cassio_suski@hotmail.com

ABSTRACT: This research studies the effects of plasma-nitriding and titanium carbonitriding mixtures on the wearing resistance of mechanical forming dies for special fixing elements manufacturing. The main focus is the abrasion wear rate, characterized by the friction between the surfaces of the raw material and die.

Three different configurations were used for the VF 800AT steel dies, chosen among the ones that had shown high waste rates before coating.

Industry and laboratory trials were performed to compare the wear behavior.

The coated dies had better results in contrast with others. The plasma-nitriding dies (with a small white layer) showed lower wear resistance (higher wear rate) when compared with titanium carbonitriding dies. That was caused by the excellent hardness of the titanium carbonitriding and the good adherence.

Key-words: Nitriding, carbonitriding, steel VF 800AT, white layer.

RESUMO: Este trabalho teve por objetivo estudar o efeito do tratamento de nitretação por plasma e do revestimento de carbonitreto de titânio sob o aspecto de resistência ao desgaste de matrizes de conformação mecânica de elementos especiais de fixação. O enfoque principal está centrado na taxa de desgaste por abrasão, caracterizado pelo atrito de elementos interfaciais entre as superfícies da matéria-prima e da matriz.

Foram utilizadas três matrizes de VF 800AT diferentes, das quais duas apresentavam desgaste excessivo antes do tratamento ou revestimento superficial, e uma apresentava problemas de fratura.

As propriedades mecânicas foram avaliadas através de ensaios de estereoscopia, dureza, microdureza, rugosidade, metalografia óptica e eletrônica de varredura e controle dimensional por carta de Controle Estatístico de Processo – C.E.P..

No estado tratado por nitretação a plasma, as matrizes (com camada branca bastante reduzida) apresentaram menor resistência ao desgaste (maior taxa de desgaste), ao passo que a maior resistência ao desgaste foi das matrizes com revestimento de carbonitreto de titânio. Isto foi atribuído a excelente dureza do elemento titânio, juntamente com seu poder de aderência, em contraste com a fragilidade da camada branca formada pela nitretação a plasma.

Palavras-chave: nitretação a plasma, carbonitreto de titânio, VF 800AT, camada branca.

1. INTRODUCTION

Tool wearing has direct influence on the efficiency, finishing and quality of products. Therefore, this is a critical point, when considered the aspects of tool components recovery, occurrences of tool fractures and undesirable production line stops. Moreover, the industry production growing speeds push the search for higher efficiency level of manufacturing. One of the main causes of tool wearing is the friction between contact surfaces by relative sliding. In general, with some exceptions as for braking, the wear coefficient and pressure must be as low as possible to reduce tool wearing.

The mechanical forming industry is continually investing on the development of wear resistant materials. The targets are the improvement of materials' properties and new materials development. New materials have been developed and

upgraded for different applications. However, research and development of new steels usually involve high investments, besides the risk factors [1, 2].

Materials performance can be improved through special operations of re-fusion and processing, however in some cases the cost-benefit ratio worsens. Surface engineering has been used as an alternative cheaper method to improve tribological properties of conventional materials and specifically to raise forming tools performance [3].

Nitriding and Physical Vapor Deposition (P.V.D.) coating techniques have been used for some time and are still on development. These processes have been extensively used to change the tool surface strength.

Surface treatments and coatings elevate surface hardness, fatigue strength, tensile friction and corrosion strength of steels, resulting in better efficiency for the forming process,

tool life and final product quality. Coatings are promising resources, considering both, technological and economical aspects. Compared to quenched and tempered materials, without coating, for example, the nitriding and titanium carbonitriding (TiCN) coatings offer better results, because of higher surface hardness and introduction of compressive residual stresses, able to improve the toughness of heat-treated materials. [4, 5]. Although production costs of components grow with coating processes, there is a gain in cost-benefit ratio, due to the augmented tool life.

This research studies the effect of coating on wearing resistance of cold mechanical forming dies of VF 800AT for special fixing elements manufacturing, aiming to increase the tool life and to reduce the production idle time.

For comparison purposes, three surface conditions were used: only quenched and tempered; with plasma nitriding; and with carbonitriding (TiCN) – P.V.D.

2. EXPERIMENTAL PROCEDURES

The investigated material is VF800 AT steel (0,85 % C; 0,90 % Si; 0,40 % Mn; 8,00 % Cr; 2,00 % Mo; 0,50 % V). The laboratory tests were done according to ASTM G65 standard. A cylindrical tool, shown in figure 1, was used for wear evaluation at industry.

Three different surface conditions were used, namely: only quenched and tempered, with plasma nitriding and with carbonitriding (TiCN) – P.V.D. The only quenched and tempered surface condition will be named as ‘**reference condition**’ in this paper.

The laboratory basic test procedure was the contact between a rotating wheel - at a specific speed - with the specimen. The specimen dimensions are: 1” (width), 3” (length) and 0,12 – 0,5” (thickness). The wheel is a metallic disc lined with rubber, as shown in figure 2.

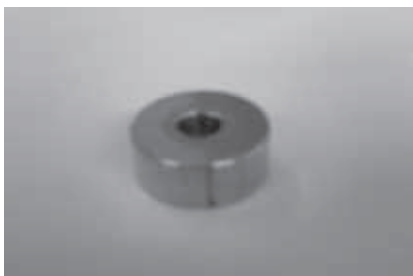


Fig. 1. Die used for industry tests (25 mm of diameter).

Two specific testing procedures were used, named “B” and “C”. The longer duration, procedure “B”, is recommended for tool steels and the shorter duration procedure “C” for surface layers wear observation. In order to use the same specimen to both tests, the following method was adopted: The 10 minutes test time of procedure B was divided in two steps: a 30 seconds “C” procedure, followed by a 9 minutes and 30 seconds test time. After the first 30 seconds the specimen was removed and ultra-sound cleaned. The mass loss was evaluated. Then the specimen was retested during the remaining time, and afterward cleaned and evaluated with respect of mass loss in the same way as before.

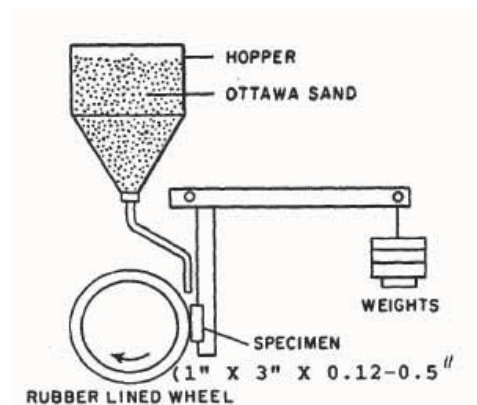


Fig. 2. Schematic of wear test assemblage and specimen dimensions [6].

Granulation sand 50 (0,30 mm), at approximated flux of 350g/minute was used for the tests. The disc velocity was set at 200 r.p.m.

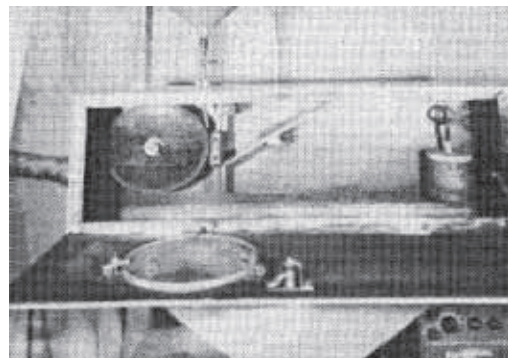


Fig. 3. Wearing test apparatus [6].

The tool used for mechanical cold forming process, in industry evaluation, reduces the raw material diameter under pressure in a 3-station machine (Yern Yao and Hilgeland machines).

In order to determine the wear of mechanical cold forming dies, three measurements of the component diameter were taken, using external micrometers, at 20 minutes time intervals. An operator registered the arithmetic mean of the measured values on a statistic control process card – S.C.P. The results were analyzed between 87 and 373 hours of effective work (without setup). The tool wear growth was indicated by the increase of the component diameter.

The inferior and superior limits allowed for the dimensional fluctuations were 7,08 and 7,13 mm, respectively.

Microstructural analysis usual routines were used for metallography preparation of the specimens. The chemical revelation was made by Nital 5 % (95 % etilic alcohol and 5 % nitric acid). The micrographic analysis was made by optical microscopy, using an 84342 – Neomet Union, and by scanning electron microscopy, using a Philips XL30.

These analyses allow verifying the steel microstructure and the coating layers, to measure the size of layers and compare with other performed tests.

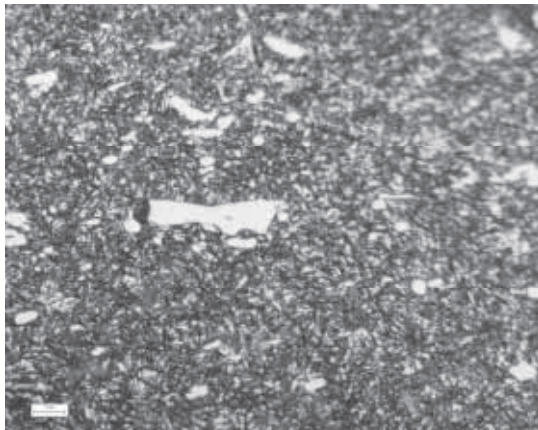
The wearing surfaces of specimens and tool were analyzed by scanning electron microscopy.

3. RESULTS

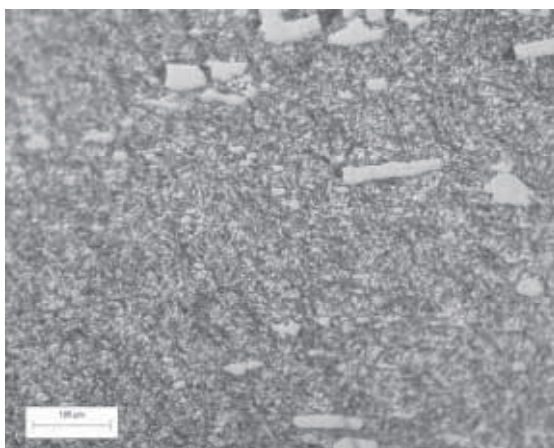
3.1. MICROSTRUCTURE CHARACTERISTICS

The substrate microstructure shows the martensite with some primary carbides (figure 4) in all cases. The similar aspect of substrates indicates that probably there are no variations for the base metal wearing.

The metallographic analysis shows that the plasma nitrated thickness is up to 15 μm (nitrides + diffusion layer), as shown in figure 5 (a). The layer of nitrides has approximately 2,5 μm and the diffusion layer around 12,5 μm , figure 5 (b). The white layer was maintained very thin in order to avoid possible coating brittleness during extrusion [3].

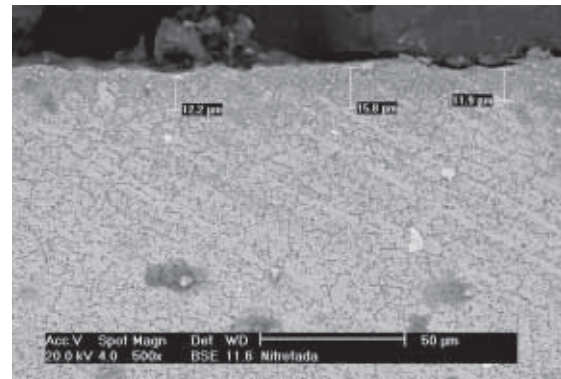


(a)

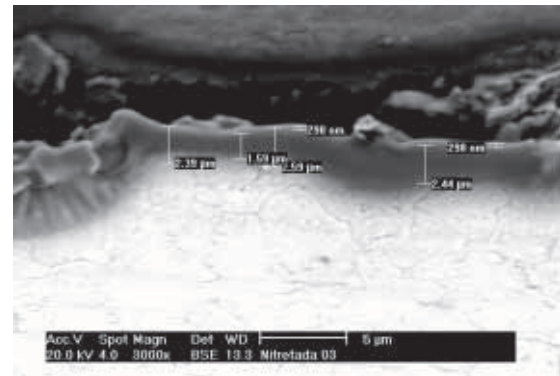


(b)

Fig. 4. Microstructure (a) and (b) of the VF800 AT steel quenched and tempered, at different scales.



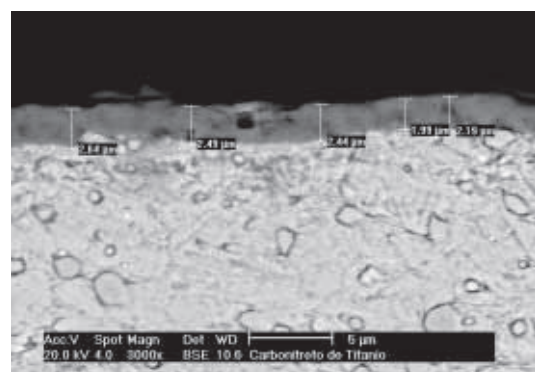
(a)



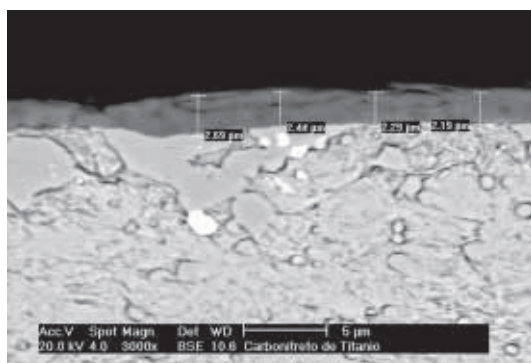
(b)

Fig. 5. Micrography of VF800 AT steel with plasma nitriding (a) – Thickness of the nitride layer, (b) – Thickness of the white layer.

The thickness of the TiCN varies from 2 to 3 μm , as shown in figure 6. This layer is thinner than the plasma nitrated layer. But, the thin TiCN layer brings up an excellent wearing resistance because of the high hardness of the titanium carbonitriding [7].



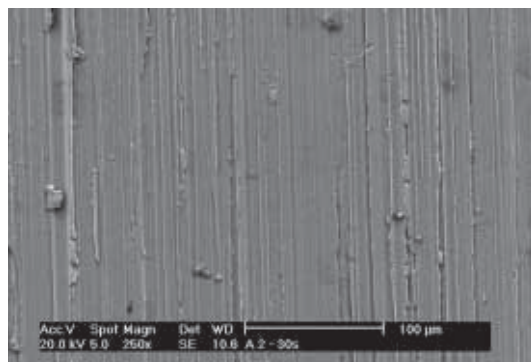
(a)



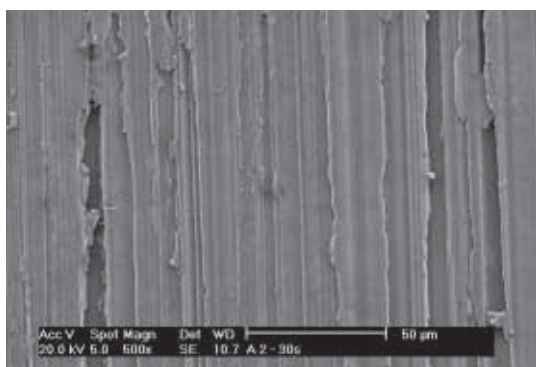
(b)

Fig. 6. Micrography of VF800 AT steel with titanium carbonitriding coating, at different regions (a) and (b).

The tool and specimens analyzed after the test revealed abrasive wear with microgrooves [8], figure 7.



(a)



(b)

Fig. 7. Surface aspect of VF800 AT steel after test, showing microgrooves.

3.2. LABORATORY WEARING TEST

The results of the wearing test based on ASTM G65 are shown in table 1 and figure 8. A life increase of 30,77 % and 97,97 % was observed for the nitriding and titanium carbonitriding specimens, respectively, when compared with reference condition specimens, for the first thirty seconds.

The superior life of the coated specimens, as compared with reference condition specimens, table 1 and figure 8, is probably associated with layers higher hardness and good adherence of layers to the substrate [9, 7].

The wearing difference between the nitriding and titanium carbonitriding, figure 8, can be associated to the higher hardness of the TiCN and the smaller thickness of the white layer nitriding specimen [9, 10], resulting in a layer with lower abrasion resistance. This layer is worn out after 30 seconds of testing. For the posterior nine minutes and thirty seconds, the life differences for nitriding and TiCN coating were (-4,61 %) and (9,28 %) respectively, when compared with reference condition specimens.

Based on ASTM G65, the test may present results fluctuation up to 7 %, which indicates no significant wear variation of the nitriding specimen, as compared with reference condition specimen. The wear for the titanium carbonitriding coated specimens was smaller.

The above results may be associated with coating behavior during the first thirty seconds. For nitriding specimens the layer should be totally eliminated and the posterior test run should act only on the steel substrate. However, for the titanium carbonitriding specimen the coating was not totally eliminated in the first thirty seconds, leaving a remaining layer of coating that significantly increased the specimen's life.

For the entire test time (10 minutes) there was a 1,43 % life decrease for nitriding specimens, taking reference condition specimens as standard, figure 8. According to ASTM G65 this difference is not significant. The life increase in the first thirty seconds for nitriding specimens is not sufficient to affect significantly the wear after ten minutes.

For the entire ten minutes test, TiCN specimens had 17,27 % life increase compared to reference condition specimens. This result shows the strong influence of coating on the specimens wearing resistance. The influence was expected to be effective only for the first seconds of the test (when the coating was not yet eliminated), but it was found that significant effects occur up to the ten minutes of the entire test time.

Therefore, two different behaviors were observed: a considerable life increase for coated specimens compared with reference condition specimens (procedure C – thirty seconds); and maintenance of life time for the substrate test (procedure B – ten minutes), figure 8.

Table 1 – Mean volume loss for abrasive wearing test.

	Volume Loss (30 sec)	Volume Loss (9,5 min)	Total Volume Loss (10 min)
VF800AT – Without Coating	6,5 mm ³	65,7 mm ³	72,2 mm ³
Nitriding	4,5 mm ³	68,73 mm ³	73,23 mm ³
Life increase compared to uncoated	30,77 %	- 4,61 %	-1,43%
Titanium Carbonitriding	0,132 mm ³	59,6 mm ³	59,73 mm ³
Life increase compared to uncoated	97,97 %	9,28 %	17,27 %

3.3. WEARING TEST AT INDUSTRY

The industry wearing of cold mechanical forming tools, evaluated by statistical control charts, revealed high wear for quenched and tempered tools (= reference condition tools). The wear average rate has linear behavior, with values around 0,0006 mm/h, as shown in table 2 and figure 9. For nitriding and titanium carbonitriding tools the average rates were 0,0002 and 0,0001 mm/h, as shown in figures 10 and 11, respectively.

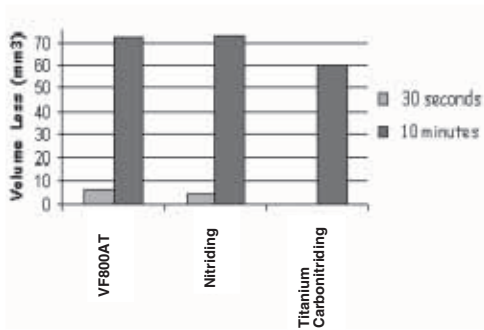


Fig. 8. Comparing volume loss on procedure C (30 seconds) and B (10 minutes) - abrasive wear.

Table 2 – Results of tool wear for industry tests.

TOOLS	Average wear rate (mm/h)	Number of hours to wear according tolerance range	Quantity produced in established wear interval (pieces)
Quenched and tempered	0,0006	87	675.116
Nitrited	0,0002	251	1.908.606
Variation (%)		288,5	282,7
Titanium Carbonitrited	0,0001	373	2.863.998
Variation (%)		428,7	424,2

The nitriding and titanium carbonitriding tool wear curves presented three distinct behaviors. For the first 100 hours the nitriding tool curve showed a wear rate around 0,0002 mm/h, at a second moment a sharp rate decrease occurs, and finally the value 0,0006 mm/h is reached, as shown in figure 10, identifying the end of the coated layer. The final wear rate (0,0006 mm/h) is similar to those of reference condition tools.

For TiCN tools the wear rate is 0,0001 mm/h for the first 150 hours, followed by a smaller wear rate, and then, reaching 0,0006 mm/h, as shown in figure 11.

These results show a decrease of the coated tool wear rate, as shown in table 2.

It is noticeable a substantial increase of the number of hours worked wherein the tool dimensional limits are sustained.

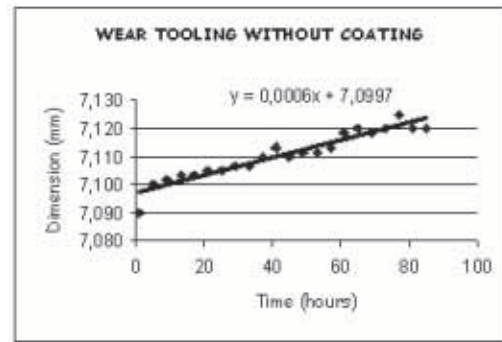


Fig. 9. Wear behavior of quenched and tempered (=reference condition) tool.

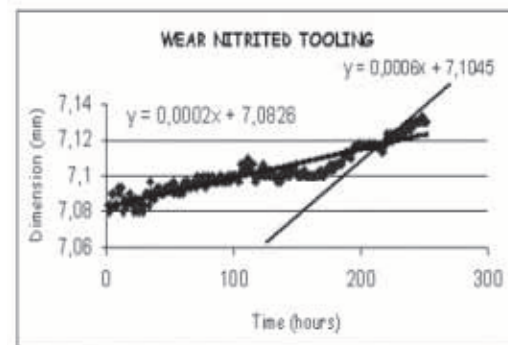


Fig. 10. Wear behavior of the nitriding tool.

The number of hours can reach 3 times as much the time for nitriding tools and 4 times for TiCN tools. In the same way, the quantity of produced parts is around 3 or 4 times bigger, correspondently, as shown in table 2. These productivity fluctuations are related to the efficiency of the machines. For nitriding or TiCN tools, machine stops for cleaning or polishing can be eliminated, due to the tools' high wear resistance and excellent surface finishing. Moreover, the work can be done at higher production velocities.

From figure 10 it can be seen that after 100 hours test run, the diameter wear value is 0,03 mm. This characteristic point represents the end of diffusion layer. In other words, this is a transition between the diffusion zone and the boundary of the substrate, which can be observed by the value of 15 µm shown in figure 6.

For TiCN tools (figure 11), the above commented region is visible too, but it occurs between 0,02 and 0,04 mm wear values. However, in this case, the transition cannot be related to the layer thickness, which is already eliminated because its thickness – 2 to 3 µm – as shown in figure 7.

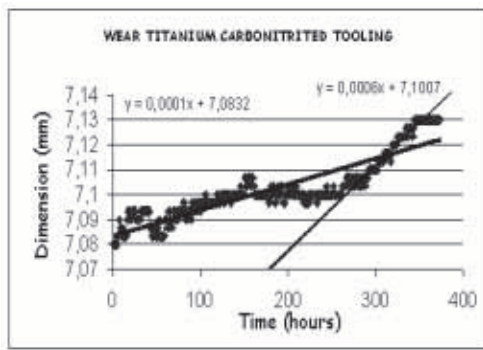


Fig. 11. Wear behavior of the titanium carbonitriding tool.

Based on these observations, it is possible to state the following hypotheses:

The high wear rate of the coated tool, at the beginning, can be linked to its own dimensional adjust, that is, the first region slope of the figures 10 and 11 can be related with tool surface imperfections. The phenomenon is probably caused by tool surface defects, which provoke an increase of nominal surface contact pressure due to the reduction of effective area [11, 12].

It is assumed that the lifetime difference between the plasma nitriding and TiCN tools may be reduced using nitrite layers thicker than 15 μm . On the other hand, the increased thickness may cause fragility to the layer, enlarging the wear.

4. CONCLUSIONS

The study main conclusions are listed bellow:

TiCN coatings produce higher layer stability, with better wear resistance than plasma nitriding.

TiCN coating is perfectly adequate for cold mechanical forming tools, increasing significantly their life, as compared with the plasma nitriding tools. The same can be observed for specimens' testing.

In spite of the small nitrite layer, the plasma nitriding process is suitable for coating cold mechanical forming tools. The life of the nitriding tools is significantly higher than lives of quenched and tempered tools. However, the tool life is lower than the corresponding value for TiCN.

Based on the microstructures analyses, a bigger thickness of the plasma nitriding tools (compared with the TiCN coating) was observed. Furthermore, because of the chosen parameters a reduced white layer for nitrides was possible.

It was identified a significant life increase of the nitriding and TiCN specimens (when compared with reference condition specimens) for the test initial thirty seconds run. In contrast, after the first thirty seconds, the life increase was smaller, leading to conclude that probably the layers were eliminated in the first seconds of the assays.

5. ACKNOWLEDGEMENTS

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