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Corrosion Assessment of Cast Aluminum Parts in Ethanol Fuel Blends

Pun WIROT[1], Jaroon TROSET[2], Witsanupong KHONRAENG [2], Sasawat MAHABUNPHACHAI[2*], Ekkarut VIYANIT[2]

[1]*Department of Materials Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand*
[2]*National Metal and Materials Technology Center (MTEC) Pathuthani, Thailand*

Abstract

Nowadays, the use of ethanol fuel blends in automobiles has become more and more worldwide since the ethanol mixture would enhance the performance of the engine and fuel economy ($/mile), while reducing the hazardous exhaust released to the environment. However, the use of ethanol fuel blends may induce some material compatibility issues on some automotive parts that were not designed to be used in contact with ethanol. In other words, the humidity in the ethanol would cause corrosion problem on these parts. The goal of this study is to assess the corrosion value of two cast aluminum parts in a motorcycle, which are cylinder head and carburetor. Sample specimens were prepared from the two aluminum parts, then immersed in three different ethanol fuel blends, containing ethanol at 20 (E20), 85 (E85), and 100 (E100) vol.%, testing at two different temperature levels (room and 50°C). Based on the immersion test results, corrosion was observed on the surface of the specimens, and determined to be a pitting corrosion type. The weight loss and depth of pit were measured after 1, 2, and 4 weeks. From the measurement results, higher weight loss and deeper pit depth values were found in the case of fuel blends with a higher ethanol content (E100 > E85 > E20) and at a higher temperature level (50°C > 25°C). As time progressed, the corrosion also continued on (i.e., higher weight loss and deep pit depth), but at a slower rate (i.e., lower weight loss and pit depth occurred during a later week). This slower rate may have been caused by the formation of oxide film at the surface of the specimens, which acts as a protective film and prevent further corrosion into the material. Nonetheless, the weight loss and pit depth values on both aluminum parts under the selected testing conditions used in this study were still within an acceptable range for the utilization of these parts with ethanol fuel blends in a motorcycle.

Keywords : Ethanol, Fuel Blends, Corrosion, Aluminum

Introduction

The use and application of ethanol fuel blends in automobiles have been consistently increasing in the past decade due to various advantages that the fuel blends possess when compared to regular gasoline. For instants, it has been reported in previous studies(1-7) that the use of ethanol fuel blends would enhance the spark ignition performance and provide anti-knock mechanism in an internal combustion engine, reduce the amount of hazardous exhaust released to the air, and, perhaps, the most important factor for switching to ethanol fuel blends, provide better fuel economy (i.e., 1.5-5% cost reduction when using ethanol fuel blends of 10-30 vol.%).

In Thailand, the use of ethanol fuel blends has also been encouraged by the

E-mail address:sasawatm@mtec.or.th

government and all major petroleum enterprises. Currently, there are already 25 gas stations selling E85 fuel blend (Ethanol : Benzene = 85 : 15 vol.%) for flexible fuel vehicles (FFV) in Thailand, and more than 430 stations for E20 fuel blend already in service nationwide. On the other hand, the E10 (a.k.a., Gasohol 91 and 95), the blend grade that has quickly gained popularity from the car users since any car models can use this fuel without any modification, is being served at every gas station already in Thailand.

In any case, while most of the recent automobile models are already designed to be E20-ready, only a few models can be fueled with E85 (e.g., Volvo S80 & C30, and Mitsubishi Lancer EX). And at the moment, these two fuel blend grades are not compatible with any motorcycle in the market.

Therefore, the scope of this study is set to investigate the effect from using E20 and E85 in a motorcycle, focusing particularly on assessing the corrosion problem on a couple cast aluminum parts that are in contact with the fuel blends in a motorcycle. Specifically, these two selected parts are the cylinder head and the carburetor. The investigation was carried out using immersion test with E20, E85, and E100 fuels at two different temperature levels (room and 50°C) during three different time intervals (i.e., 1, 2, and 4 weeks).

Materials and Experimental Procedures

Materials

New spare parts of motorcycle cylinder head Figure 1 and carburetor Figure 2, obtained from a local automotive retail store, were cut into small pieces in a size of 10x10x5 mm^3 and 5x5x3 mm^3, as shown in Figures 1 and 2, respectively. These small pieces were later grinded on all faces and submerged in containers filled with different grades of ethanol fuel blends.

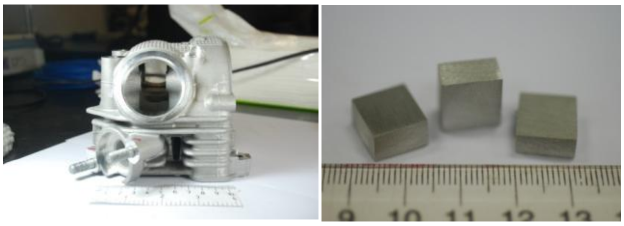


Figure 1: (left) Cylinder head of motorcycle, and (right) sample specimens.

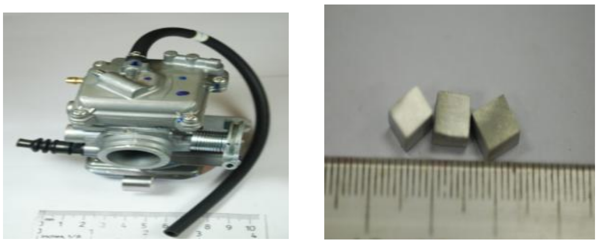


Figure 2: (left) Carburetor of motorcycle, and (right) sample specimens.

A Spark Emission Spectrometer was used in order to analyze the chemical composition of these cast Aluminum parts prior to the test. For each part, three measurements were performed and the average values are summarized in Tables 1 and 2, respectively.

Immersion Tests

Prior to the immersion tests, all specimens were grinded with sand paper number 80, 120, 320, 400, and 600, then washed by ethanol and dried by hot air. After that, the specimens were weighted and their weights were recorded, and then immediately dropped to the bottom of beakers that contained different ethanol fuel blends (E20, E85 and E100). This process was performed in less than 1 minute for each sample in order to prevent the possibility of oxide film formation at the surfaces of the specimens.

To control the temperature of the fuel blends during the test, a heating plate and a circulating water bath Figure 3 were used to maintain the temperature at 50°C, while the other half of the beakers were placed in a controlled temperature room which has the room temperature set at 25°C at all time during the testing period up to 4 weeks. To prevent the fuel blends from drying out due to evaporation, especially at the higher temperature level, each beaker was covered and sealed at the top by Parafilm. For each test condition, two repetitions were used to ensure the accuracy and repeatability of the test results. The immersion tests were conducted according to ASTM standards.[8-9]

Table 1: Chemical compositions of cylinder head and standard Al320.0

Samples	Chemical compositions (Wt.%)						
	Si	Cu	Fe	Mg	Mn	Ni	Zn
Standard Al 320.0	5.0-8.0	2.0-4.0	Max 1.2	0.05 -0.6	Max 0.8	Max 0.35	Max 3.0
Cylinder Head	7.9	2.1	0.7	0.3	0.2	0.06	0.5

Table 2: Chemical composition of carburetor and standard Al383.1

Samples	Chemical compositions (Wt. %)						
	Si	Cu	Fe	Mg	Mn	Ni	Zn
Standard A383.1	9.5-11.5	2.0-3.0	Max 1.0	0.1-0.2	Max 0.5	Max 0.5	Max 2.9
Carburetor	10.81	1.48	0.79	0.2	0.25	0.07	0.74

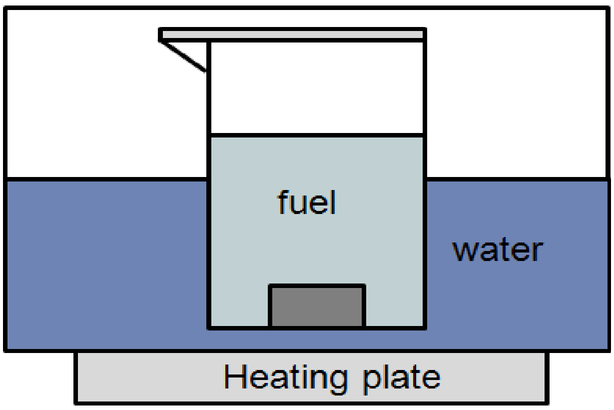


Figure 3: Schematic drawing of immersion test setup.

Weight Loss and Surface Analysis

After each selected time interval (i.e., 1, 2, and 4 weeks), the specimens were removed from the beakers and cleaned according to the ASTM G1[10] by using an aqueous solution that is composed of 50ml phosphoric acid (aq), 20g chromium trioxide (solid), and dilute with water to 1000ml. The cleaning aqueous solution was heated up to 90-95°C before submerging the specimens to be cleaned for 5-10 minutes. Then, the specimens were scaled for weight loss measurement, analyzed the surface topology by using a Scanning Electron Microscope (SEM), and measured the depth of pit.

Depth of Pit Measurement

Measurement of pitting corrosion depth was performed by using a reflected light microscope that is equipped with a laser sensor for accurate vertical distance measurement as shown in Figure 4. As the microscope stage is moved up or down, the laser sensor will provide a distance reading in the z-axis. Therefore, by focusing the microscope at the top face of the specimen and then move the focus to the bottom of the pitting hole, the depth of the pit can be read off from the laser sensor. For each specimen, twenty measurements were performed and the average values were reported.

Results and Discussion

Weight Loss

The weight loss measurements of cylinder head and carburetor specimens are shown in Figures 5 and 6, for both temperature conditions at 25ºC and 50ºC. Based on these results, it is clear that there were some weight losses on both cast Aluminum parts; and thus, corrosion had occurred on these materials.

Figure 4: Microscope equipped with laser sensor.

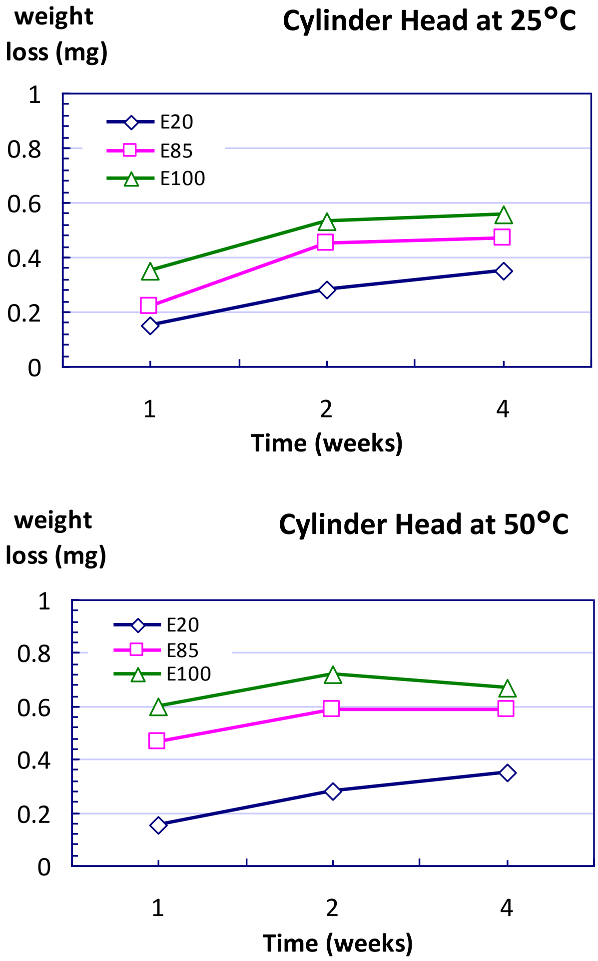


Figure 5: Weight loss of cylinder head at (top) 25 ºC, and (bottom) 50ºC.

When considering the effect of the submerged time on the weight loss, it was observed that the specimens would continue to lose more weight as time progressed, but it happened so at a slower rate. In other words, the amount of the weight loss was the highest during the first week, and this number was reduced during week 2, 3, and 4. This lower amount of weight loss (i.e., lower corrosion rate) during the later weeks is believed to be due to the formation of oxide film on the specimen surface; and thus, preventing further corrosion into the material and slowing down the corrosion rate. [11-13]

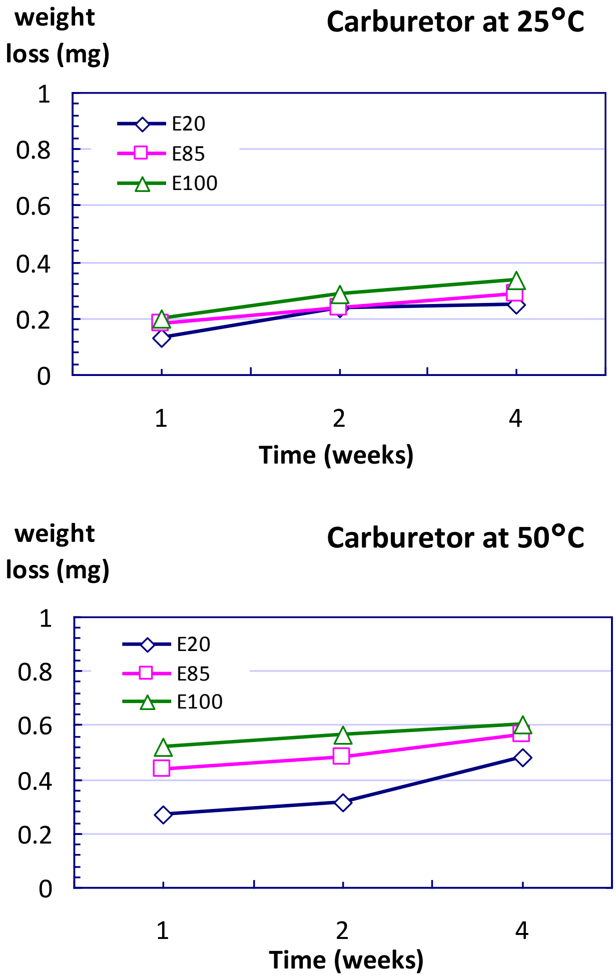


Figure 6 : Weight loss of carburetor at (top) 25 ºC, and (bottom) 50ºC.

Furthermore, based on the weight loss results as shown in Figures 5 and 6, it can be concluded that ethanol fuel blends that contain a higher ethanol content would cause more weight loss (i.e., corrosion in E100 > E85 > E20). Finally, the higher temperature level also increases the amount of the weight loss (i.e., corrosion at 50ºC > 25ºC) on both Aluminum parts tested in this study.

Surface Analysis

The surface topologies of different specimens from cylinder head and carburetor were examined using SEM and shown in Figures 7 and 8, respectively. The grinded surface shown in the top pictures in Figures 7 and 8 revealed smooth surface of the specimens prior to the immersion tests, while the bottom pictures showed the corrosion that occurred on the surface of the specimens. According to these high magnification images, the corrosion type was identified to be that of a pitting corrosion(14-16) which scattered all over the surfaces of all specimens that were submerged in all three types of fuel blends since the first week of the test. However, the amount of these pitting corrosion marks was found to be denser and more scattered on the specimens tested with fuel blends containing higher ethanol contents (i.e., pitting amount in E100 > E85 > E20).

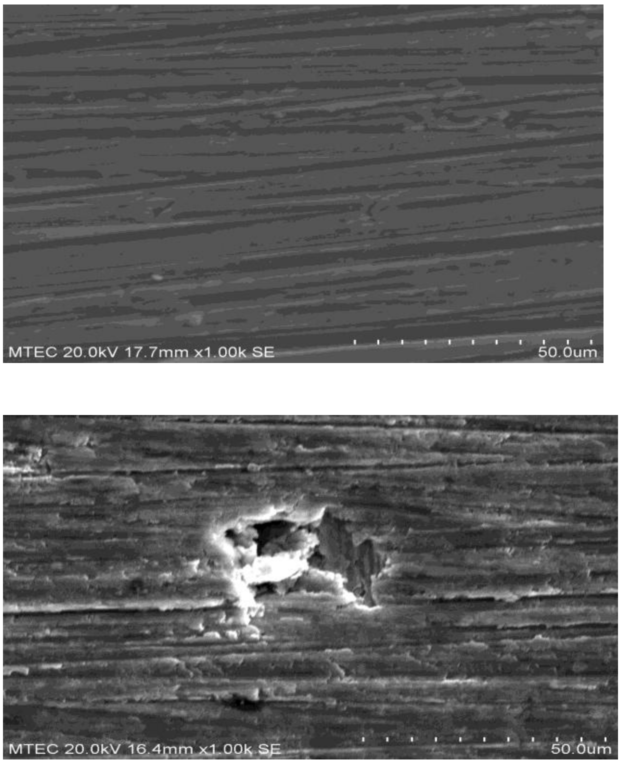


Figure 7: Surface of cylinder head specimens before (top), and after (bottom) the immersion test.

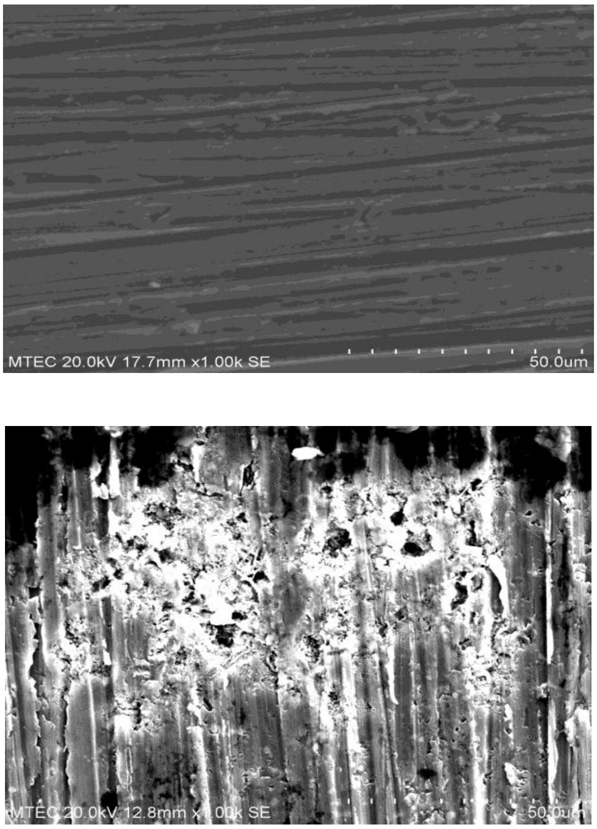


Figure 8: Surface of carburetor specimens before (top), and after (bottom) the immersion test.

In addition, temperature was also showed to have some effect on the amount of the pitting corrosion as well. That is a larger area of pitting corrosion was observed all over the specimens tested at 50°C when compared to 25°C, given all other test conditions are kept the same. Besides the pitting corrosion marks, a small number of large pitting holes were also observed at certain locations on some specimens. The most severed pit is shown in Figure 9 for a carburetor specimen tested in E100 at 50°C.

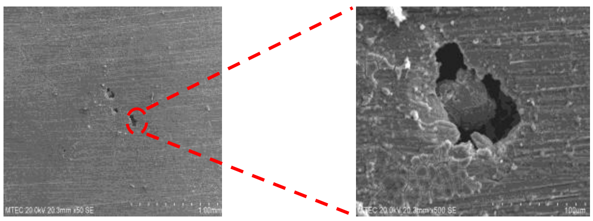


Figure 9: Most severe pitting hole

Depth of Pit

In order to quantify the severity of the corrosion on the two cast Aluminum parts under different testing conditions, the depth of pit were measured on each specimen. For each sample, twenty measurements were carried out and the average value from each testing condition is plotted in Figures 10 and 11.

Based on the measurement results, the depth of pit appears to be deeper in fuel blends with higher ethanol contents (i.e., E100 > E85 > E20). In addition, the value of pit depth was shown to increase with increasing time. However, the pitting rate was found to be slower as time progressed (i.e., the highest pit depth value occurred after the first week, and continue to decrease in week 2 and 4). This can be explained by the formation of oxide film after the first week as well. Finally, only a slight effect of the temperature was found on the depth of pit as the values of the pit depth in most cases were quite similar, except for the cylinder head specimens in E20 where the higher temperature appeared to significantly increase the pit depth. In any case, the values of the pit depth for all specimens measured in this study were between 1-5 micrometers. And the maximum value of pit depth was found on the specimens that were submerged in E100 after 4 weeks.

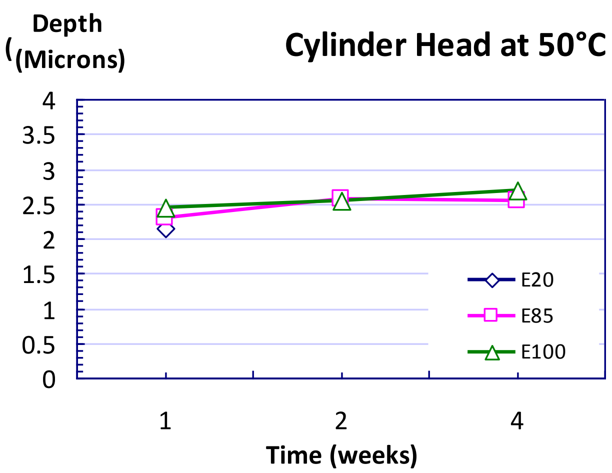
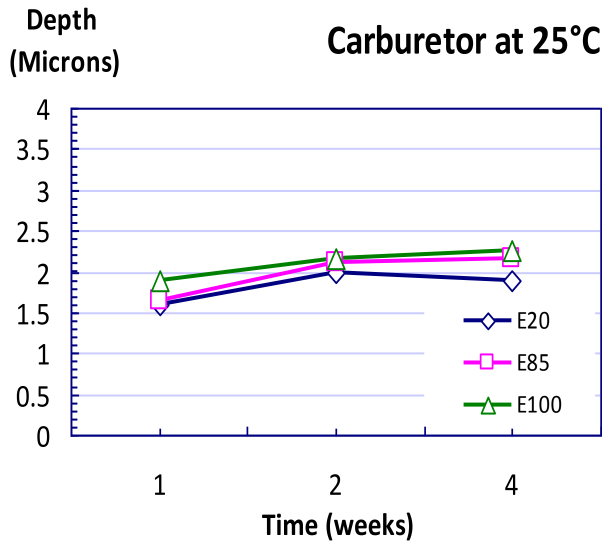


Figure 10: Average depth of pit for cylinder head at (top) 25ºC and (bottom) 50ºC.



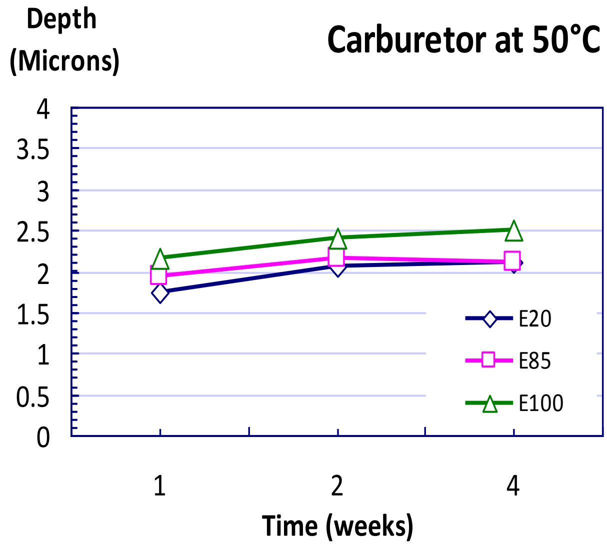


Figure 11 : Average depth of pit for carburetor at (top) 25ºC and (bottom) 50ºC.

Conclusion

In this study, pitting corrosion was found on both cast aluminum parts when leaving them in contact with ethanol fuel blends both at room and elevated temperature levels. Corrosion had occurred since the first week and continued onward, but at a slower rate during a later time, which is likely due to the formation of oxide film at the surface of the specimens after a certain period of time. In addition, it was found that a high temperature level also stimulates the occurrence of corrosion. Finally, the corrosion appeared to be more severed in Al320.0 (cylinder head) than in Al383.1 (carburetor) under the same testing condition. Nevertheless, based on the weight loss and depth of pit values from both cast aluminum parts under the selected testing conditions used in this study, it can be concluded that the pitting corrosion that occurred on these parts were still within an acceptable range; and thus, these parts should be able to be safely used with ethanol fuel blends or even pure ethanol (E100).

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