Effects of Acidic Food Environment Corrosion on Impact Strength of Aluminum 6061 Alloy: A Case Study with some Menus at a Cadets' Mess

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ABSTRACT: *Major inquiries about aluminum as a food contact material are its low strength and impact resistance which make it unable to take much force without breaking alongside health hazards that can be associated with daily intake of its ions in the human body in amounts above 10mg/Kg compared to many other materials. Corrosion was recognized as a serious common degradation process that can accentuate cost implications of aluminum as a food contact material in terms of these. Aluminum can corrode appreciably under acidic environments with pH less than 4. The aim behind this research work was to use accelerated corrosion test to assess corrosivity extents of some menus, namely; Akamu, Lemon juice, Okro soup, Pounded yam, and Beans amidst any peculiar acidic environments to aluminum cookware and utensil used to prepare or serve food daily to over 900 cadets at Nigerian Defence Academy cadets' mess and the effects on impact strengths of the cookware. Food grade aluminum alloy (Al 6061) was procured, ascertained and used to produce 60 ASTM impact specimens. After procedurally cleaning the specimens to similar surface finish, 5 pairs were used for control and 25 pairs each soaked for 28 days in the menu samples separately homogenized sequentially with 0, 2, 4, 8, and 10% by weight of concentrated phosphoric acid (H_3P0_4) at ambient laboratory conditions. Thereafter, the specimens were removed and tested of their impact strengths. Analysis of collated results showed strength reductions with increase in the H_3P0_4 treatment. The lemon fruit juice treated with 10% by weight H_3PO_4 caused comparatively highest but negligible impact strength reduction of 0.031% relative to the control (un-soaked) specimen value. The results understandably showed that the menu samples amidst the mess environmental conditions have insignificant effects on corrosion and impact strength of the aluminum cookware and utensils.*

Keywords: *Food materials, aluminum alloys, aluminum cookware and utensils, health-risks, strength, corrosion degradation, foods and ingredients, peculiar environments.*

I. INTRODUCTION

Corrosion studies of aluminum and aluminum alloys have received considerable attention by researchers because of their wide industrial applications and economic considerations [1]. Aluminum and its alloys have comparatively better corrosion properties than most metals but their corrosion is inevitable and can be influenced by the way in which they are used in some environments. In many applications the use of aluminum is limited due to dramatic deterioration of the corrosion properties with any effort made to increase the strength. The different possible forms of aluminum corrosion that can be encountered in some environments include pitting, crevice, filiform, erosion, cavitation, inter-granular, exfoliation, galvanic and micro-biologically influenced corrosions [1, 2]. The hardening phases and uniformly distributed fine intermetallics in aluminum and its alloy matrixes act as electrochemical heterogeneities and promote galvanic interactions with localized cause of corrosion. The chemical composition, size, number, and distribution of the intermetallics in the matrix govern the reaction of Al alloys [2].

According to the Food and Drug Administration (FDA), to be considered food-safe, a material must meet several conditions. For example, it [3-5]:

i. Should be durable, corrosion-resistant, and nonabsorbent.
ii. Should have resistance to pitting, chipping, crazing, scratching, scoring, distortion, and decomposition.
iii. Must not allow the migration of deleterious substances or impart colors, odors, or tastes to food.
iv. Should possess sufficient weight and thickness and strength to withstand repeated ware washing and forces.
v. Should be well finished to have a smooth, easily cleanable surface.

The key advantages of aluminum as a food contact material are its temperature tolerance, ability to heat and cool fast, rust corrosion resistance, light weight, good appearance and good clean-ability, fair durability, good formability properties, high reflectivity and low cost. On the other hand, aluminum has low fatigue and tensile strengths and impact tolerance compared to many other food grade materials, so it can't take much stress or energy without breaking. Aluminum can also corrode appreciably in acidic and alkaline environments outside the pH range of 4-9 and this can accentuate its weakness in strength to untimely fracture [6] with costs. Aluminum is also no innocent or benign participant in the body system. Aluminum accumulates in the kidneys, brain, lungs, liver and thyroid where it competes with calcium for absorption and can affect skeletal mineralization. In infants, this can slow growth. The sources of aluminum into human body systems are through natural contents of various levels in the foods we eat and leaching of its ions into food by corrosion and abrasion processes [7].

It is not pure aluminum or every aluminum alloy that is used for food processing and handling. When aluminum is used in the food industry, there are rules as to what the content of each aluminum alloy must be because aluminum alloys need to contain elements that completely negates the health risk of using pure or nearly pure aluminum as food contact material. In that regard, there are maximum tolerances of alloying elements laid down in connection with the use of aluminum as food contact material. The tolerances are specified by reputable authorities such as European food law. The maximum content tolerance of various elements in aluminum alloys used in the food industry as per the European food law EN 602:2007 is given in Table 1 [8].

Table 1: The maximum content of various elements in aluminum alloys used in food industry [8]

Element	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Zi	Ti	Others
Max. weight content [%]	13.5	2	0.6	4	11	0.35	3	0.25	0.3	0.3	0.15

For example, Al 6061 alloy is a commonly used food aluminum alloy and has elemental weight composition of: 96.85% Al, 0.9% Mg, 0.7% Si, 0.6% Fe, 0.3% Cu, 0.25% Cr, 0.20% Zn, 0.10% Ti, 0.05% Mn, and 0.05% others [9] so is a satisfactory food grade aluminum alloy according Table 8.

Aluminum pots, pans, plates and spoons are used greatly to prepare or serve large quantity of food for over 900 cadets for breakfast, lunch and dinner on daily basis at Nigerian Defence Academy cadets' mess. The foods are cooked by heating them to various temperatures between about 100 to 150^{O}C and durations of 30 minutes to two hours depending on the types and quantities of the food. Some of the mess food products require mixing with ingredients containing various levels of chemicals like chlorides, organic acids, sodium bisulfite, potassium bisulfite and sodium sulfite, which are generally known to be corrosive to metals. The foods served to cadets at the cadets' mess reflect the Nigerian food recipes which are derived from a number of grains, rhizomes, bulbs, fruit seeds, vegetables and an avalanche of fruits which have different chemical compositions and can be corrosive to aluminum. The food recipes come mainly from a selection of semi-solid dough or boiled servings prepared from cassava, plantain, yam, cocoyam, millet, beans, maize, or rice, served with typical Nigerian soups or stews. Soups and stews prepared at the mess are generally careful and deliberate blend of spices and seeds or thickeners in a broth enriched with fish and assortment of meats and leafy vegetables as desired. The ingredients used to make soups and stew include: table salt, onions, ginger, pepper, Magi, palm oil, ground nut oil, bitter leaf, tomatoes, Alayafu vegetable, Ogbono, dried okoro, ground dried melon seeds called-Egusi and many more. Meals are also served with plenty of fruits mostly of the citrus types easily grown near Nigerian homes. The commonly used corrosive element at the mess kitchen is water. Steam heating, cooling and other processing and cooking procedures at the mess require continual use of water. Facility cleanliness is a crucial part of the mess, so daily sanitization processes are conducted to meet the mess requirements, and large amounts of water are used in daily wash down procedures. These sanitization processes often use chemical cleaning solutions containing various levels of acids, alkaline, and chloride and can be corrosive to aluminum containers and utensils used at the mess [10].

The aim behind this research article was to understand whether some commonly prepared foods served to cadets at NDA cadets' mess namely; Akamu, citrus fruits (Lemon juice), Okro soup, Pounded yam, and Beans and general exposure environmental peculiarities of the cadets' mess are significantly corrosive and inimical to impact strengths of aluminum cookware and utensils used at the mess as one of their mechanical properties that is cherished and should be safeguarded to avoid untimely breakages of the cookware with loses during their usage. The main objectives of the research were:

i. To contribute to understanding the quality of aluminum containers used to prepare or serve food to cadets at NDA cadets' mess with respect to corrosion resistance.

ii. To contribute to provide any upfront useful information to industrial manufacturers of aluminum pans, plates, spoon, pots, cans and trays generally for in strategies for improving qualities of their products.

iii. To contribute insight into the safety level of aluminum ion concentration present in the menu samples since any corrosion due to them can cause leaching of aluminum ions into food and frequent intake of aluminum ions into the body system above the level of 10mg/Kg can be health-hazardous to humans [10,].

II. METHODOLOGY

Procurement and Ascertainment of Aluminum Alloy 6061

The aluminum was purportedly bought in rod forms of diameters 18mm and lengths 4m from a commercial dealer in Zaria, metropolis in Nigeria. The rods were analyzed by elemental weight compositions to find out whether they were indeed the Al 6061 alloy with the Energy Dispersive X-ray fluorescence analysis. The Minipal 4 facility manufactured by Pan-analytical Limited Netherlands and metal powders ground out at different sections of the rods were used in the analyses. Plate I shows a side view of the chemical analyzer used and plate II the procured rods used. The analysis confirmed that the rods were indeed Al 6061 alloy with average percentage [%] elemental weight composition shown in Table 2.

Table 2: Average elemental weight chemical compositions of the procured aluminum

Element	Ti	Mn	Cu	Fe	Si	Mg	Cr	Al	Others
Composition [%] weight	0.093	0.051	0.298	0.613	O.752	0.914	0.249	96.90	The Balance

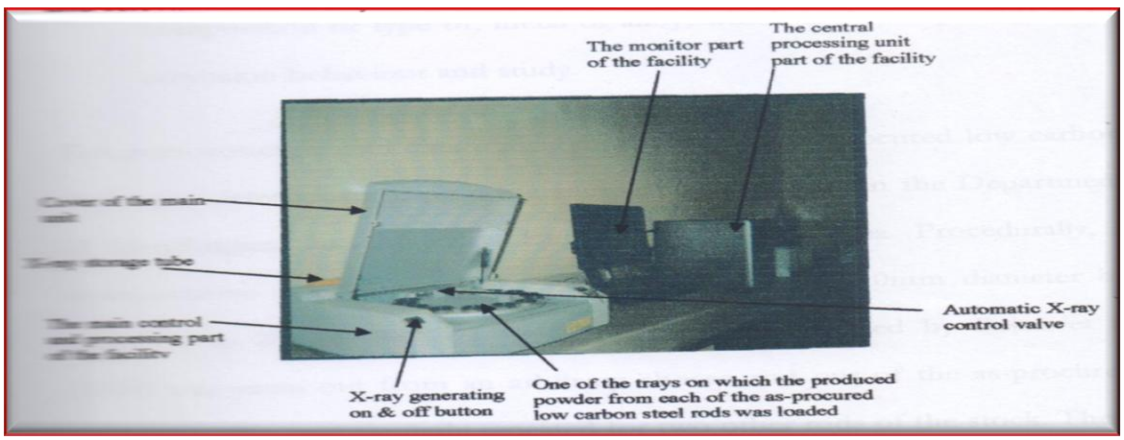

Plate I: A side view of the Minipal 4 facility used to analyze chemical composition of the AL rods

Plate II; The procured aluminum rods used for the research

Production of the Impact Specimens

After ascertaining that the procured aluminum rods were Al 6061 alloy, they were used to machine-produce 30 pairs of ASTM impact specimens. This was achieved by sawing the rods out into lengths of 62mm and further machining them on the lathe into the required shape sizes of the ASTM standard specimens shown Fig 1 [10]. The specimens were produced with a lathe machine in a commercial machine shop in Kaduna metropolis Nigeria. Plate III shows the machinist in the process of machining the specimens on the lathe.

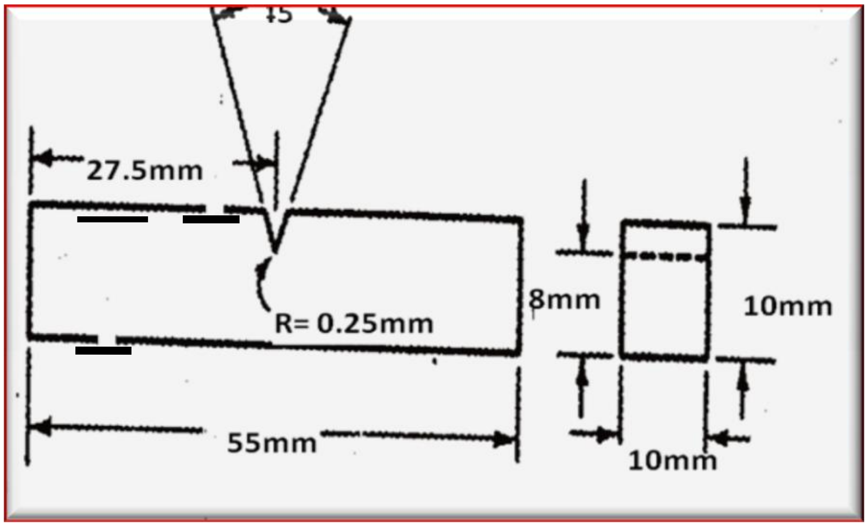

Fig: 1: ASTM: Standard Impact Specimen [11]

Plate III: Machinist in the process of producing the specimens on the lathe

Cleaning the specimens

A smooth file was first used to scrub off all machining burrs on the specimens. The specimens were then successively hand cleaned with abrasive emery cloth of grit 280, 190, and 120 in that order, together with occasional cleaning off of attached particles with a clean hand towel in the process. The finally polished specimens were then rinsed under cold tap water and cleaned by dipping them into a solution of 70% HNO_3 in a 1000ml plastic beaker for 2-3 minutes at room temperature. The dip-cleaned specimens were rinsed in distilled water. After that the surface water on them was wiped with a lint-free towel. The specimens were thereafter suspended in an oven warmed to 125 °F (52 °C) to dry them. In all cases all clean specimens were duly handled with gloved hands. These were carried out according to the ASTM-G1 procedure for cleaning metals for corrosion tests [12]. Plates IV and V show the specimens after machine-producing them and after cleaning them respectively.

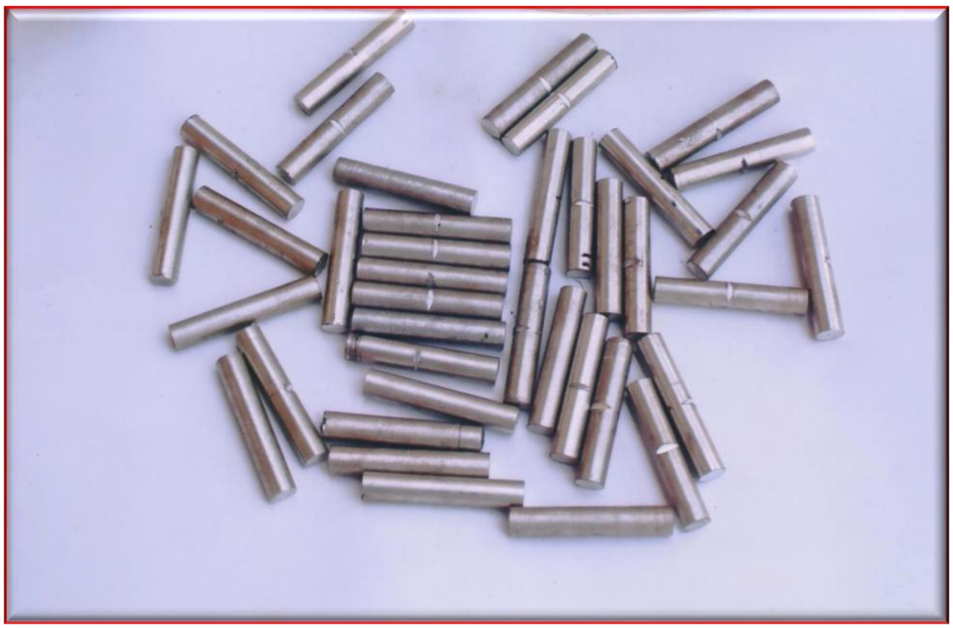

Plate IV: Some of the produced impact specimens before cleaning them

Plate V; Some of the specimens after cleaning them

Exposure of Specimens to the Food Media

25 pairs of the cleaned aluminum specimens were each soaked in the laboratory at ambient conditions continuously for 28 days in the separate food samples homogenized sequentially with 0, 2, 4, 8, and 10% by weight of concentrated phosphoric acid (H_3P0_4) in separate clean plastic containers and left open to air at room temperature of 23-27^{O}C. After soaking them, the specimens were removed and tested of their impact strengths.

Impact Test of Specimens

Impact test of the prepared samples were determined in accordance with the American Society of Metals (ASM) procedure using the Hounsfield balanced impact testing apparatus used for measuring impact strength. Each specimen was held appropriately in the vice of the apparatus so that it was just a simple beam supported at the ends. The specimen was struck behind the V-notch by two released pendulums each of mass 2.443kg travelling at a standard speed of 5m/s with a kinetic energy of 149.2 Joules in opposite directions from their calibrated standard height to fracture the specimen. The energy remaining after fracture was determined in each case from the height of rise of each pendulum and its weight. The difference between the energy input and energy remaining represented the energy absorbed by the specimen. In that way data was collected from the tests and reported as the respective specimen averages as soaked in the food media samples. The facility used for impact-testing of specimens was as shown in Plate VI.

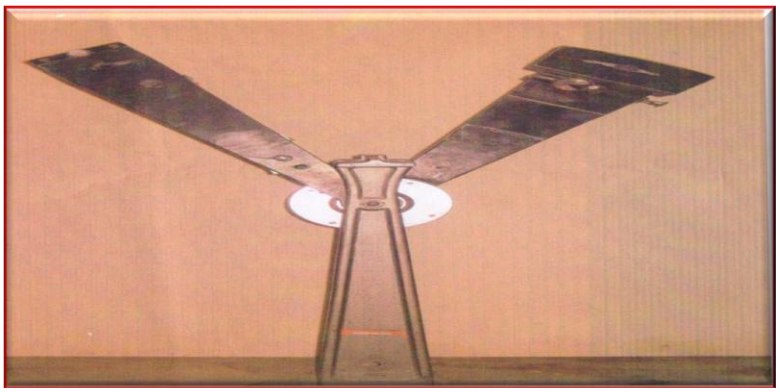

Plate VI: The impact testing facility used

III. RESULTS AND DISCUSSIONS

Food media Corrosion test Results

Test results of impact strengths of the Al 6061 coupons with respect to the various media prepared with the study food samples and H_3PO_4 are shown in Fig. 2. The percentage reduction (PR) in impact strength due to corrosion effects of the media on each coupon was determined from the data in Fig. 2 using equation 1 [13, 14]

$$PR = \left[\frac{IS^{C} - IS^{UC}}{IS^{UC}}\right]100\% \quad \dots\dots\dots\dots (1)$$

Where $IS^{C}. and\ IS^{UC}$ are the impact strength values of the control (un-corroded) and soaked specimens in the menu media samples for 28 days respectively. The entire result was as presented in Table 3. The levels and pattern of variation of the reductions in the impact strength is shown in Fig. 3.

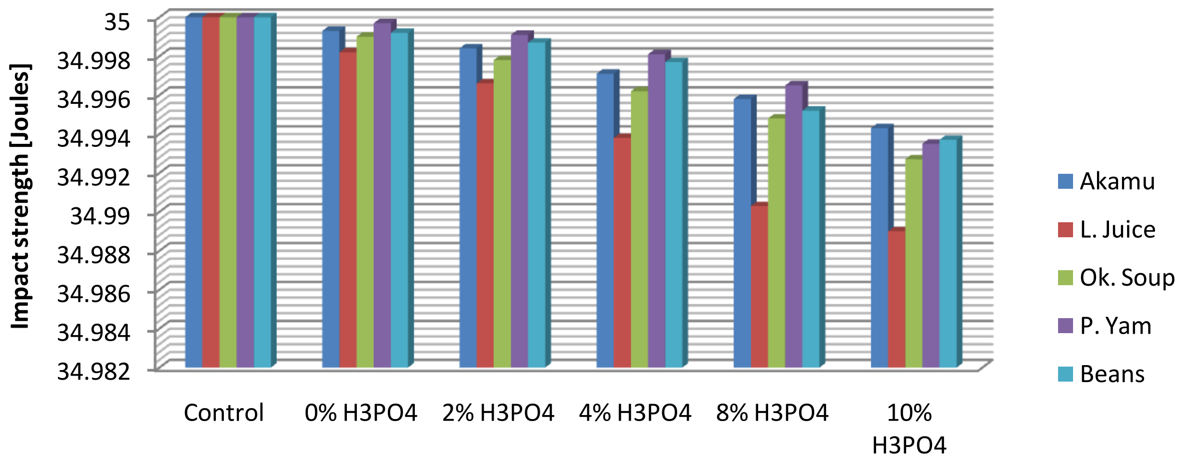

Fig. 2: Impact strengths (Joules) of Al 6061 alloy coupons after they were soaked for 28 days in the specified food samples from NDA cadets' mess treated with 0-10% H3PO4

Table 3: Reduction [%] of impact specimens after they were soaked for 28 days in the food samples treated with specified weight [%] of concentrated H_3PO_4.

Food samples	H_3PO_4 treatment by weight [0-10%]				
	0%	2%	4%	8%	10%
Akamu	0.002	0.004571	0.00829	0.012	0.016286
Lemon Juice	0.0051	0.00971	0.01771	0.0277	0.031
Okro Soup	0.00286	0.00629	0.01086	0.014857	0.02086
Pounded Yam	0.000857	0.00257	0.00543	0.01	0.01857
Beans	0.002286	0.00371	0.006571	0.01371	0.018

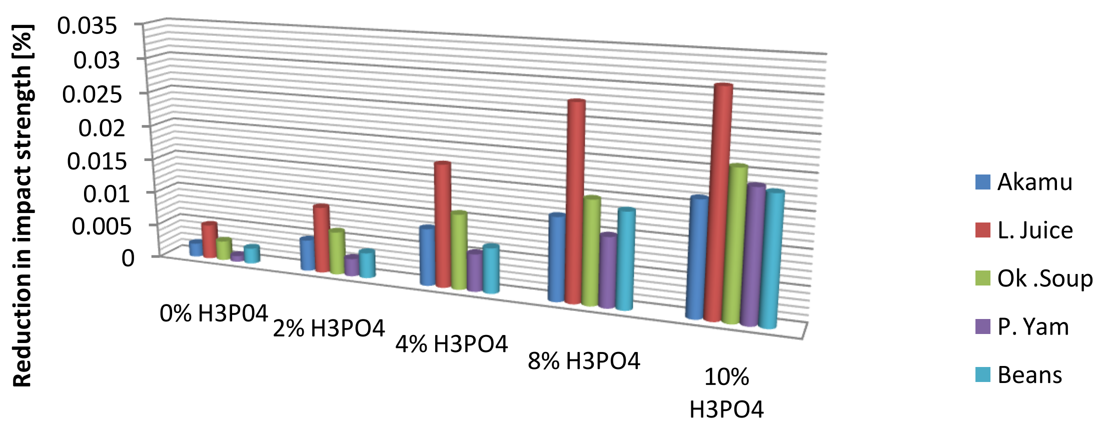

Fig 3: Pattern of variation of percentage reductions in impact strengths of specimens soaked for 28 days in the specified food samples treated with the specified wt [%] of H3PO4.

Discussion

From the results presented in Figs. 2 and 3 and Table 3, it is observable that the prepared media samples with the five menus from the cadets' mess have effects on corrosion and impact strengths of the Al 6061 alloy coupons. The food media samples without phosphoric acid treatment have the least effects. The effects increases with increase in treatment of the food samples with 0 to 10% by weight of phosphoric acid as can be observed from Figs. 2 and 3 and Table 3. Pounded yam that was not treated with the acid caused the least impact strength reductions of 0.000857% and the lemon juice treated with 10% of the acid the highest reduction of 0.031% of the aluminum coupons as can be seen from Table 3. In totality, the lemon juice exhibited comparatively highest corrosion effect on the coupons, followed by Okro soup, Akamu, Beans, and Pounded yams as can also be observed from Figs. 2 and 3 and Table 3. The reason attributed to the corrosivity variation among the food media samples is in the pH levels of the food types per se since some of them can be more acidic than others. By this, increase in the same H_3PO_4 treatment concentration increased acidity contents of the prepared food sample media to different levels and made them to cause different corrosion levels of the aluminum coupons according to their respective pH levels. Fruits generally have pH in the range of 2 to 5 and vegetables in the range of 3 to 6 and are more corrosive than most other foods [7]. Lemon juice is a fruit menu, that could be why it was most corrosive and pounded yam might have been a menu with more near neutral pH than the other food samples so least corrosive. The results however clearly show that each of the prepared food media samples caused corrosion of the aluminum coupons and affected their impact strengths but minimal as can be seen from Table 3 and Fig. 3. The general average atmospheric corrosion rate of aluminum and its alloys is about 0.06µm/yr and is considered very insignificant [1]. From this, it is also inferable that the impact strength reduction of 0.000857% to 0.031% of the tested Al 6061 samples by NDA cadets' mess menus amidst ambient acidic environment is also insignificant. This by implication shows that under ambient conditions the study food samples have negligible effects on corrosion of Al 6061 alloy and hence on aluminum containers and utensils used at the NDA cadets' mess.

IV. CONCLUDING REMARK

Corrosion is an unavoidable damaging natural phenomenon that affects all areas of human technological and economic progress including food processing equipment, containers, and utensils [15, 16]. It was noted that aluminum containers and utensils were being used to prepare breakfast, lunch and dinner for over 1000 cadets on daily basis under peculiar environmental exposure conditions at NDA cadets' mess. The foods served at the mess reflect the general Nigerian food recipes which are derived from a number of grains, rhizomes, bulbs, fruit seeds, vegetables and an avalanche of fruits. It was thinkable that some of them could be corrosive with adverse effects on the containers and utensils and cause leaching of aluminum ions into them. Accelerated corrosion study of corrosivity levels of Akamu, Lemon juice, Okro soup, Pounded yam, and Beans menus as some the commonly prepared and served menus to cadets at the mess was therefore conducted to understand impact strength integrity level of Al 6061 as a common food grade alloy amidst the menus and any peculiar acidic exposure environment at the mess. Obtained test results and analyses understandably indicated that the food samples amidst any exposure environment of acidic contents up to 10% at the mess have negligible effects on corrosion and impact strength of aluminum cookware and utensils used there.

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