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EFFECT OF HYBRID NANO MATERIAL (Ti+Cu) ADDITION ON CORROSION–FATIGUE INTERACTION AND ELECTRICAL PROPERTIES

Hussain J. M. Al-Alkawi Abduljabbar Owaid Hanfesh Saja Mohammed Noori Mohammed Raouf
Alalkawi2012@yahoo.con aljabbara.2007@yahoo.com sema.semo@yahoo.com
Electromechanical Engineering Department, University of Technology, Baghdad

ABSTRACT

This research is devoted to study the influence of different weight percent concerning to the additions of Ti and Cu on corrosion- fatigue and electrical properties of AA6061. The composite materials consist of different weight percentage of Ti (0.2, 0.4, and 0.6) and constant weight percentage of Cu (0.2) are fabricated by liquid metallurgy route technique.Attempts have been made to explore the impact of corrosive media on the fatigue behavior of AA6061 submerged for 80days in shat al Arab water. Constant and variable corrosion fatigue tests are performed under rotating bending loads and stress control at the stress ratio R= -1 and room temperature (RT). The results show the fatigue strength reduction due to corrosion without nano materials increases with the increasing of the testing cycles, but when adding nano material the fatigue strength reduction will be reduced with increasing the testing life. Furthermore the results of electrical tests show that increasing electrical conductivity and decrease of resistivity.

KEYWORDS:HybridNanoComposites,DryFatigue,CorrosionFatigue,Electrical Conductivity, Resistivity

تأثير المادة النانوية الهجينة (Ti + Cu) المضافة على تداخل تآكل الكلال والخصائص الكهربائية

حسين جاسم محمد العلكاوي عبد الجبار عويد حنفيش سجى محمد نوري محمد رؤوف
الجامعة التكنولوجية/ قسم الهندسة الكهروميكانيكية

الخلاصة

يتضمن البحث الحالى دراسة تأثير اضافة نسب وزنية مختلفة للمواد امتناهية الصغر Ti,Cu الى سبيكة الاساس على الخواص الميكانيكية والترايبولجية وتداخل التأكل الكيمياوي الكلالي والموصفات الكهربائية لسبيكة المادة الاساس حيث كان المركب النانوي يحتوي على قيم مختلفة لـTiوهي 0.2%,0.4%,0.6% مع ثابت النسبة الوزنية لـCu ب 0.2% وتمت تصنيع النماذج بطريقة السباكة. تم اجراء فحوصات التأكل الكيمياوي الكلالي للسبيكة AA 6061 بعد غمرها لمدة 80 يوم في ماء شط العرب . الفحوصات التي اجريت كانت من نوع ثابت سعة ومتغيرة السعة (الضرر التراكمي) لتداخل التأكل الكيمياوي الكلالي عند نسبة اجهاد R=-1 ودرجة حرارة الغرفة (RT) النتائج اظهرت نقصان في مقاومة الكلال نتيجة للتأكل الكيمياوي الحاصل من ماء شط العرب بينما التركيب النانوي مبدأ النقصان في مقاومة الكلال يقل بزيادة عمر الفحص.بينما اظهرت نتائج الفحوصات الكهربائية تحسن واضح في الخواص الكهربائية زيادة في التوصيلية الكهربائية ونقصان في المقاومية.

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INTRODUCTION

During the past few decades aluminum matrix composites (AMCs) with nano particles as reinforcement materials have received a wide attention due to their good mechanical and electrical properties. Furthermore, they composites are lightweight materials, thus they are widely used in structural, automotive industrial and aerospace[**Jeyasimmane et al ,2014**].AMCs containing two or more reinforcement materials have found commercial application because they can be manufactured economically by conventional methods. Moreover, they are distinguished by feasibility, enhance strength, elastic modulus and low density[**Mohsen et al ,2011**].Many studies have demonstrated that aluminum alloy 6061 can be used as metal matrix for fabrication the nano composites by adding different nano materials with it.**Alkawi et al [2018],** investigated the fatigue behavior of 6061-T6 aluminum alloy under constant and variable amplitude loading in air for as- received and pre-corroded specimens in 3.5% NaCl corrosive solution for 77 days. For unpenned specimen fatigue strength curve was decreases by 4.5% due to the immersed the specimen. The improvement of the fatigue life and corrosion life of specimens when applying of ultrasonic peening was 8.69% and 2.3% respectively for high and low sequences. **Al-Alkawi et al [2018],** studied the fatigue behavior of 6061-T6 aluminum alloy under constant amplitude loading in air for as-received and pre-corroded specimens in 3.5% NaCl corrosive solution for 77 days. The results showed that the tests of fatigue life on pre-corroded specimens with and without ultrasonic peening revealed a significant reduction in life before cyclic loading. In state of un peened specimens the constant S-N fatigue strength curve was decreased by 4.5% due to immersed the specimens in corrosive 3.5% NaCl solution for 77 days, while in state of ultrasonically peened specimens the reduction of S-N curve decreased to 2.2% due to the beneficial effect of this treatment for increasing the corrosion-fatigue life. **Sahandia et al [2016],** investigated the results on the fatigue characteristic of Al-matrix nano composites produced via friction stir processing method. An Al-Mg alloy (AA5052) together with various amounts (~2 and 3.5 vol %) of pre-position TiO2 nanoparticles were speed up to 6 to gain homogenous scuttle of nano-metric implying. It was located that FSP of the aluminum alloy raised the fatigue strength for about 28% and 32% matched with the annealed sample when the focusing of the strengthening particles was 2and 3.5 vol%, individually. **Saheb et al [2017],** studied the electrical conductivity properties of Al_2O_3-SiCCNT hybrid Nano. High-resolution millimeter were utilized to gauge the electrical conductivity. The Al_2O_3-5SiC-2CNTs had a max electrical conductivity value of 8.85 S/m matched to a low number of 6.87 x 10-10 S/m for alumina. The addendum of SiC and CNTs to alumina lowers its average temperature thermal properties. These properties were reconditioned with the microstructure. **Liu et al [2015],** used aluminum alloys as very good conductor, their usage to electric and electronic manufacturing was fixed because of low strength. A new planning of micro-structural purpose for improvement mixing of electric conductive and strength in Al alloy was developing based on modulation of the progression of classical cold distortion Al matrix and suitably utilize the work-solidify impact to decompensated the loss of age-solidify impact due to the harden of the solidify remaining in the materials disruptions and remaining forming by solutes separation acting as commanding strengthening elements with the later. **Velmurugan et al [2011],** investigated metal matrix composites. Electrical discharge machining (EDM) shows a good method for machining MMCs. Hybrid Al6061 metal matrix composites strengthened with 10% SiC and 4% graphite particles. Composites were manufacturing utilizing stir casting technique. Metal elimination rate of the composite raises with maximize in present, fixed pulse and pressure of the dielectric fluid while it minimizes with maximize in voltage. Tool wear rate of the advanced composite increases with maximize in current and voltage and it minimizes with raise in fixed pulse and pressure of the dielectric fluid. The object of the study is to ascertain the effects of hybrid nano reinforcements on the corrosion- fatigue and electrical properties of AA6061. Design of experiments were set using different test machines, consisting of bending rotating fatigue (Schench) testing machine, LCR meter device.

1. To study the corrosion-fatigue interaction of aluminum alloy (6061) containing of different weight percentage of nano titanium (Ti) (0.2,0.4,0.6) wt.% keeping copper(cu) 0.2%wt
2. To study electrical properties such as electrical conductivity , resisitivity

EXPERIMENTAL WORK

Rotating Bending Fatigue Test Machine

The fatigue tests were carried out using a bending rotating fatigue (Schench) testing machine as per (DIN 50113) standards [H. J Alalkawi et al ,2015]. Figure (1) shows the samples of fatigue according (DIN 50113) [H. J Alalkawi,2015]. Fatigue and corrosion fatigue tests were conducted on AA6061alloy (base metal) and the AA6061hybrid nano composites containing different weight percentage of Ti+Cu with constant loads and variable loads at R=-1. The speed of the testing was selected as 1420 r.p.m. Figure (2) structure of fatigue test rig is shown. Fatigue corrosion samples were corroded in shat al arab water for 80 days. All tests are conducted at laboratory temperature.

Electrical Testing

The L.C.R meter is an electrical Device used to measure capacitance (C), inductance (L) and resistance (R) of the circuits and components at various frequencies. The device shows these electrical characteristics, L.C.R meters can be also show dissipation factor (D), phase angle (θ), impedance (Z), equivalent series resistance (ESR) and quality factor (Q). Some L.C.R meters shows conductance, admittance and its components, and susceptance. Electrical properties such conductivity and resistivity ,were conducted on AA6061 alloy (base metal)and hybrids composites containing different weight percentage of Ti and cu. The tests were done in Ibn al-Haytham College by the L.C.R meter device at range of frequency 50HZ-5MHZ. Figure (3) shows LCR meter.

RESULTS AND DISCUSSION

Fatigue and Corrosion Fatigue Results

Table (1) shows the fatigue cycles for constant amplitude loading and corroded at shat al Arab water for 80 days .In order to make comparison between metal base and hybrid nano composites with different weight percentage of Ti+Cu. prior to fatigue tests, corrosion tests were performed on fatigue specimens at room temperature (25^{o}C) during continuous immersion times of 80 days .Constant fatigue life and corrosion- fatigue life tests were carried out using 23 HZ since wave with a stress ratio R= -1 .The results of stress level (σ_f) as a function of the number of cycles to failure (N_f) i-e S-N curves were obtained using several stress levels (from 70 to 120 MPa) were considered. The constant S-N curves results, table (1), are plotted in figure (4) for eight types of testing. The Basquin equations derives from the experimental work can be illustrated in table (2) with the correlation coefficient (R^2).

Concerning the corrosion –fatigue, most works focused on the 6XXXand 2XXX aluminum alloy. Interaction between corrosion and fatigue are infrequently considered. The fatigue life and the reduction of fatigue strength after pre-corrosion tests is mostly indicated to crack initiation from surface pits formed through previous immersion in Shatt al Arab water. [Dolley et al ,2000] presented a corrosion- fatigue results obtained from immersion the samples in Nacl solution 384h. . They concluded that fatigue strength and life decreased by increase the time of immersion forAA2024-T3 alloy. The main reason of reduction was correlated with time of exposure to the corrosive surrounding. Addition of nano materials to the aluminum alloy leads to reduce the above reduction as it can be seen in next sections.

Fatigue Strength of Corrosion – Fatigue Interaction without Nano

Table (3) gives the evaluation of fatigue strength due to corrosion for 80 days in shatt Al- Arab. The S-N curves and Basquin equations can be shown in the below table, while Fig (5) illustrates the behavior of AA6061 metal matrix with and without corrosion.

It is clear that the results of table (3) and figure (5) explained how the corroded media of Shatt al Arab influence on reducing the fatigue strength of AA6061 metal matrix. Corrosion has reduced the fatigue property of the alloy. The reduction is due to pitting at the surface and corrosion reduce the S-N curve level as shown in fig (5). The endurance fatigue limit at 10^7 cycles was measured from Basquin equation for the unreinforced alloy AA6061 as given in table (4) with 5.98% reduction in endurance fatigue limit due to corrosion defects.

Fatigue Strength Reduction Due To Corrosion (FSR %) without Nano Materials

It can be said that corrosion embrittles the AA6061 alloy. This embrittlement is due to superficial deformation of the specimens. The results of table (3) indicate that increasing the testing cycles leads to increase the fatigue strength reduction (FSR%) i-e increases from 0.98 at 10^4 cycles to 2.857 at 10^5 cycles to 4.93 at 10^7 cycles for unreinforced alloy. The FSR% increase in approximately linear manner. Figure (6) illustrates the variation of FSR% against testing cycles. The experimental results revealed that the fatigue strength of corroded samples exhibits significant increasing in (FSR%) related to the presence of corrosion defects as illustrated in figure (6).

Fatigue Strength of Corrosion-Fatigue Interaction with Nano Materials

According to experimental results of tensile, hardness and wear testing the best behavior was occurred when added (0.4Ti+0.2Cu) wt% to the base metal AA6061. Then the comparison will be made on this type of composite in two cases, dry and corroded as given in table (5). The experimental results of composite tested under constant corrosion-fatigue interaction revealed that significant decreasing in FSR% related to presence of nano reinforcement materials which play a major role in reduction the FSR% when the fatigue testing cycles increased. The endurance fatigue limit of 0.4%Ti+0.2%Cu composite was measured from Basquin equation in dry and corroded condition given in table (6).

The results indicate that the nano materials reduce the FSR% when increasing the testing life in a linear trend as shown in figure (7). These improvements may be due to uniform distribution of nano materials, high bounding between AA6061 and (Ti+Cu) and high mechanical properties of the nano material particles itself. The effect of nano materials added to the AA6061 on fatigue behavior a rises the S-N curve level as shown in figure (8).

ELECTRICAL PROPERTIES RESULTS

Frequency Dependence Conductivity:

The AC Electrical conductivity is the major parameter for conducting materials which are using electrical engineering. The Al-Mg-Si alloy (6xxx series) is utilized as conductor for overhead power line due to of its good combination between electrical and mechanical properties when compared with AA 6061alloy, the electrical conductivity and resistivity of sample were measured using the four points technique [Heaney et al ,2000]. The specimens have been cut to circular of diameter (D) =10mm and width (W) =18mm.), while the relation between conductivity and frequencies are illustrated in figures (9).Table (7) gives the electrical conductivity at room temperature (RT) for four cases (0%wt,0.2%wtTi+0.2%wtCu, 0.4%wt Ti+0.2%wtCu,0.6%wt Ti+0.2%wt Cu)at range of frequencies (50HZ – 5MHz).

Application of conductivity equation on the present results

Applying equation to the experimental results gives the values of A_1 and S for zero nano and composites as given in table (8).

Resistivity

Conductivity and resistivity were measured with LCR meter device. Three specimens were tested for each weight percentage and the average values of conductivity and resistivity are recorded, while the relation between resistivity and frequencies are illustrated in figures (10) .Table (9) gives the electrical resistivity at room temperature (RT) for four cases (0%wt,0.2%wtTi+0.2%wtCu, 0.4%wt Ti+0.2%wtCu,0.6%wt Ti+0.2%wt Cu)at range of frequencies (50HZ – 5MHz). It is worth to mention that the above results were determined under laboratory conditions (RT 25℃ and humidity 35%).An increase in hybrids nano reinforced material content increase the electrical conductivity from 3035.395454 s/m to 11503.68887s/m for zero nano and (0.4%Ti+0.2%Cu) nano respectively. These properties were corresponded that a huge increment in electrical conductivity for Al_2O_3 -5Sic-2CNTs hybrids composites concluded that a a huge increment in electrical conductivity for Al_2O_3 -5Sic-2CNTs composite which it had electrical conductivity of 8.85 s/m contrasted with the small value of the matrix[Nouari Saheb et al, 2017].

CONCLUSIONS

In the present work, attempts have been made to develop a nano composite material with good mechanical, tribological, corrosion- fatigue and electrical properties. There are several conclusions obtained from the experimental results.

1. The fatigue strength reduction (FSR%) due to corrosion base metal (AA6061) showed approximately linear increase against the testing cycles without nano reinforcement while the (FSR%) for the nano composite exhibited almost linear reduction trend against testing cycles.
2. The reduction in endurance fatigue limit was recorded to be 5.98% for dry conditions. But this value reduced to 1.1% due to addition the hybrid nano reinforcements.
3. The maximum electrical conductivity is observed in hybrid nano composite including 0.4%Ti+0.2%Cu. While the resistivity reduced from 3.33 10^{-3} (Ω.cm) for metal matrix to 1.88 10^{-3} (Ω.cm) for 0.4%Ti+0.2%Cu hybrid nano composite.
4.

Table (1) constant dry fatigue and corrosion-fatigue interaction results

Metal matrix (AA6061)					
Dry fatigue condition				Corrosion fatigue conditions for 80 days	
Specimen no.	Applies stress σ_f MPa	N_f cycles	$N_{f\ av}$	N_f cycles	$N_{f\ av}$
1,2,3	120	1200,2500,1800	1833	1700,2004,1660	1788
4,5,6	100	2400,3800,3600	3266	2700,3600,3000	3100
7,8,9	80	41600,38000,40800	40133	28000,32600,38000	32866
10,11,12	70	120000,166000,135000	140333	101000,112000,99000	104000
0.2%wt.Ti+0.2%wt.Cu composites					
Dry fatigue condition				Corrosion fatigue conditions for 80 days	

Specimen NO.	Applied stress σ_f MPa	N_f cycles	$N_{f\ av}$	N_f cycles	$N_{f\ av}$
13,14,15	120	3000,4100,2800	3300	2000,3800,3200	3000
16,17,18	100	19000,22600,23600	21733	19600,18700,15700	18000
19,20,21	80	66000,79700,75100	73600	62800,55000,62200	60000
22,23,24	70	320000,338000,390000	349333	280000,272000,264000	272000
0.4%wt.Ti+0.2%wt.Cu composite					
Dry fatigue condition				Corrosion fatigue conditions for 80 days	
Specimens no.	Applied stress σ_f MPa	N_F cycles	$N_{F\ av}$	N_F cycles	$N_{F\ av}$
25,26,27	120	3600,5680,4600	4626	2800,3600,3200	3200
28,29,30	100	22600,24000,26800	24466	20000,18600,24400	21000
31,32,33	80	68000,81600,77000	75533	75000,66000,72000	72000
34,35,36	70	410000,392000,428000	410000	332000,305000,308000	315000
0.6%wt.Ti+0.2%wt.Cu composite					
Dry fatigue condition				Corrosion fatigue conditions for 80 days	
Specimen No.	Applied stress σ_f MPa	N_f cycles	$N_{f\ av}$	N_f cycles	$N_{f\ av}$
37,38,39	120	2800,3000,4500	3433	2700,2000,2600	3100
40,41,42	100	20000,23600,24600	22733	17000,22000,21000	20000
43,44,45	80	66800,75300,82500	74866	72000,51000,75000	66000
46,47,48	70	390000,372000,328000	363333	310000,272000,312000	298000

Table (2) shows equations of dry fatigue and corroded fatigue of hybrid nano composites and metal matrix

Material	Basquin equation $\sigma_f = AN_f^b$
metal matrix(AA6061)	$\sigma f = 267 N_f^{-0.114}$ $R^2=0.9595$
0.2%Ti+o.2%Cu	$\sigma f = 319. N_f^{-0.12}$ $R^2=0.9814$
0.4%Ti+0.2%Cu	$\sigma f = 343 N_f^{-0.125}$ $R^2=0.9749$
0.6%Ti+o.2%Cu	$\sigma f = 321 N_f^{-0.12}$ $R^2=0.9798$
corroded metal matrix(AA6061)	$\sigma f = 282 N_f^{-0.121}$ $R^2=0.9603$
corroded 0.2%Ti+0.2%Cu	$\sigma f = 326 N_f^{-0.124}$ $R^2=0.9826$
corroded 0.4%Ti+0.2%Cu	$\sigma f = 323 N_f^{-0.122}$ $R^2=0.9832$
corroded 0.6%Ti+0.2%Cu	$\sigma f = 324 N_f^{-0.123}$ $R^2=0.9814$

Table (3) comparison of fatigue strength under dry and corroded conditions without nano

AA6061	AA6061 Corroded	Comparison Of fatigue Strength			Fatigue Strength Rreduction FSR%		
Basquin equation		10^4	10^5	10^7	10^4	10^5	10^7
$\sigma f=267N_f^{-0.114}$ $R^2=0.9595$	$\sigma f=282 N_f^{-0.121}$ $R^2=0.9603$	93.43-92.52 MPa	72-70 MPa	42.5-40.5 MPa	0.98	2.857	4.93

Table (4) endurance fatigue limit at 10^7 cycles for zero nano alloy

As- received	Corroded for 80 days	Reduction factor
42.5MPa	40.1MPa	5.98%

Table (5) corrosion fatigue interaction of (0.4%Ti+0.2%Cu)wt %composite in two cases(without corrosion and with corrosion)

(0.4%Ti+0.2%Cu)wt composite		Comparison Of fatigue Strength			Fatigue Strength reduction FSR%		
dry	corroded	10^4	10^5	10^7	10^4	10^5	10^7
Basquin equation		108-105 MPa	81-79 MPa	46-45 MPa	2.85	2.53	2.22
$\sigma f=343.N_f^{-0.125}$ $R^2=0.9749$	$\sigma f=323N_f^{-0.122}$ $R^2=0.9832$						

Table (6) shows the endurance fatigue limit at 10^7 cycles for 0.4%Ti+0.2%Cu in dry and corroded conditions

0.4%Ti+0.2%Cu (dry)	0.4%Ti+0.2%Cu (corroded)	Reduction factor
45.7MPa	45.2MPa	1.1%

Table (7) maximum electrical conductivity at frequency range (50HZ-5MHZ)

Max .electrical conductivity $(\Omega . m)^{-1}$ in the range of frequencies (50 -5MHz)			
Zero nano	0.2%wtTi+0.2%wtCu	0.4%wtTi+0.2%wtCu	0.6wtTi+0.2%wtCu
3035.395454	3214.820965	11503.68887	4066.179017

Table (8) conductivity material constants for the zero nano and composites

Material	A_1	S	Conductivity equation
Zero nano	1×10^7	0.002	σ a.c=$1\times10^7W^{0.002}$
0.2%Ti+0.2%Cu	3×10^7	0.218	σ a.c=$3\times10^7W^{0.218}$
0.4%Ti+0.2%Cu	3×10^9	0.537	σ a.c=$3\times10^9W^{0.537}$
0.6%Ti+0.2%Cu	3×10^7	0.229	σ a.c=$3\times10^7W^{0.229}$

Table (9) maximum peak of electrical resistivity

Max .electrical resistivity (Ω . m) in the range of frequencies (50 -5MHz)			
Zero nano	0.2%Ti+0.2%Cu	0.4%Ti+0.2%Cu	0.6%Ti+0.2%Cu
229.8266617	90.85113115	1.885164162	27.9318125

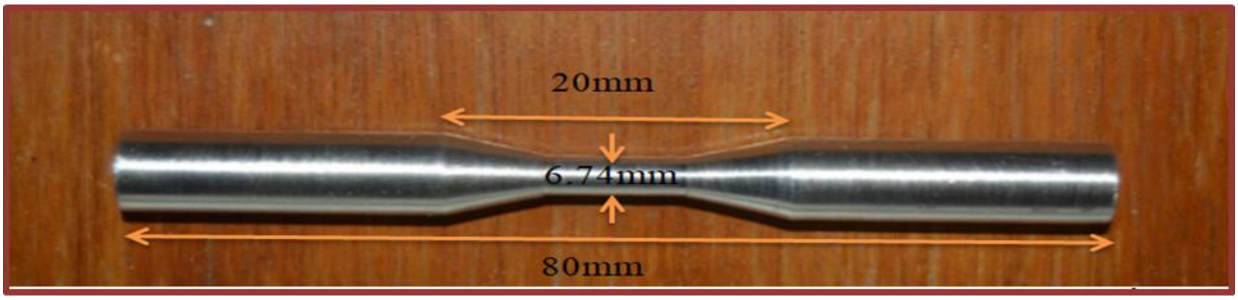

Figure (1) Fatigue specimen dimensions based on (DIN 50113)

Figure (2) rig of fatigue rotating bending

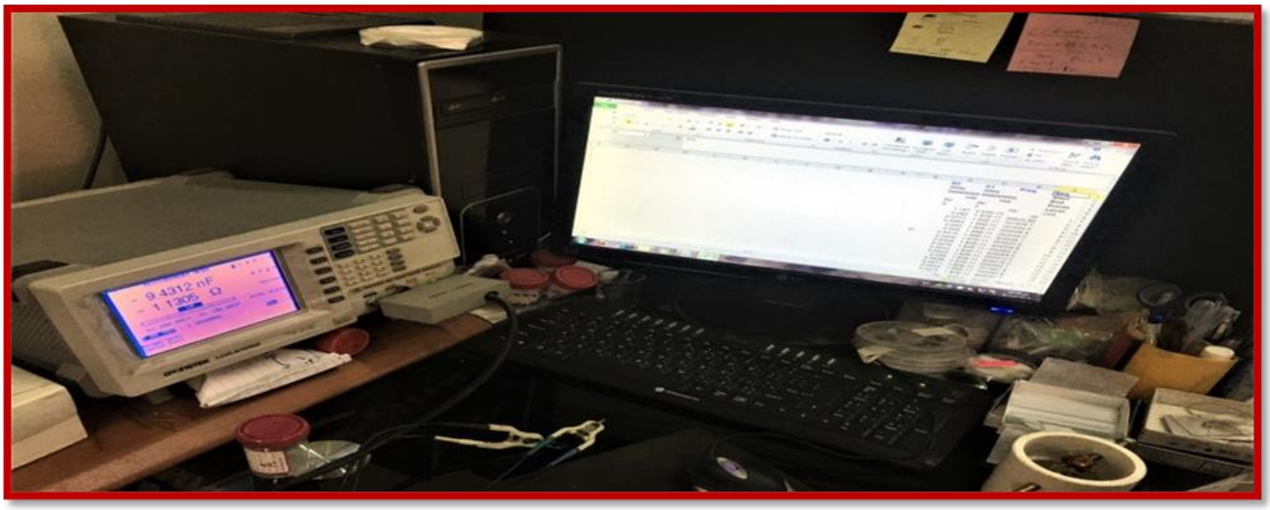

Figure (3) shows device LCR meter and test

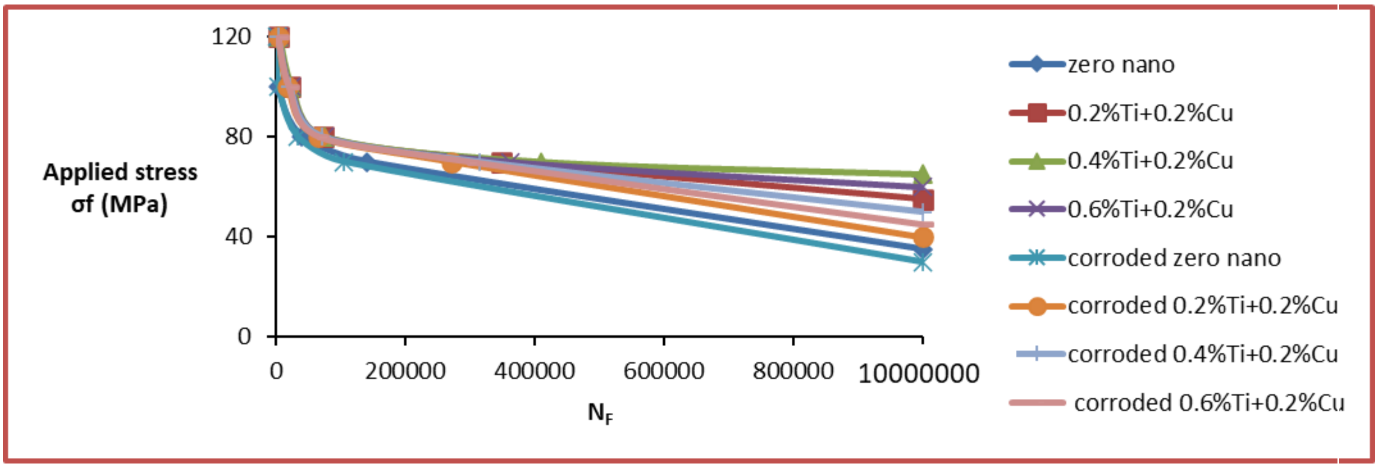

Figure (4) shows S-N curves for dry fatigue specimens and corroded fatigue specimens for hybrid composites and metal matrix (AA6061)

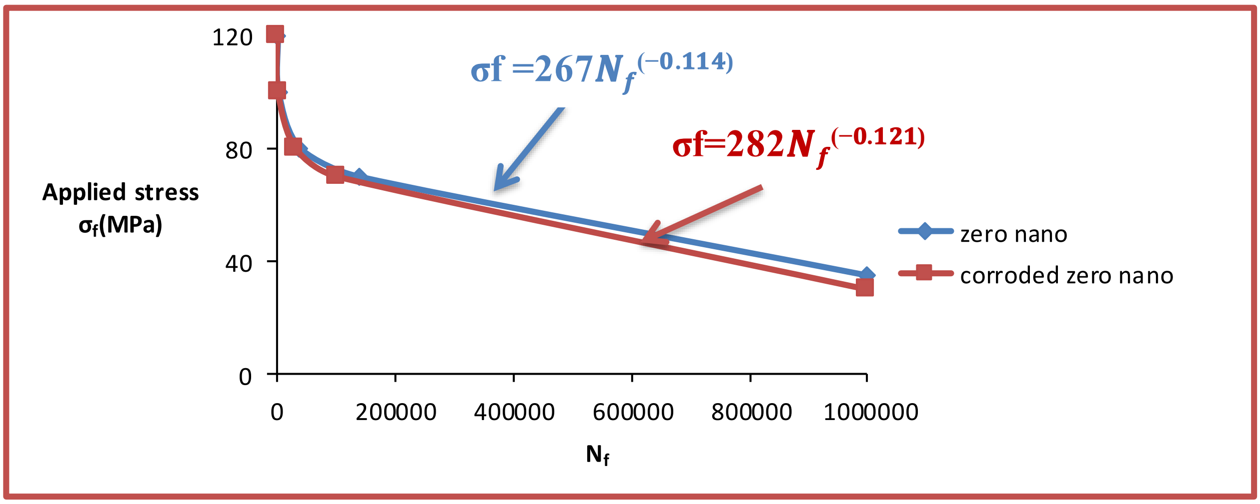

Figure (5) S-N curves for AA6061 metal matrix without nano material

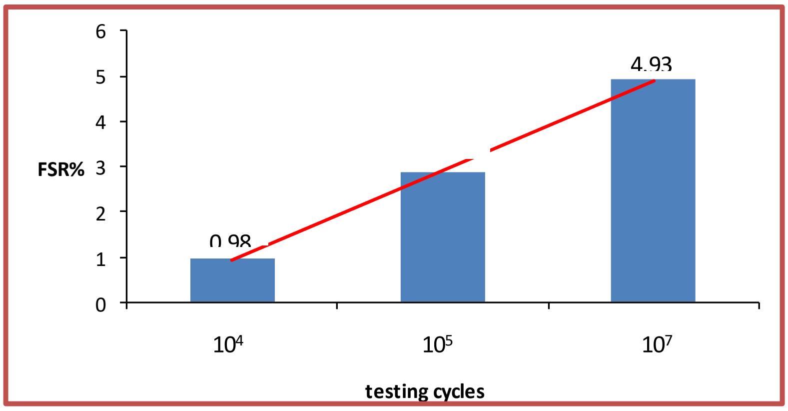

Figure (6) FSR% against the testing cycles

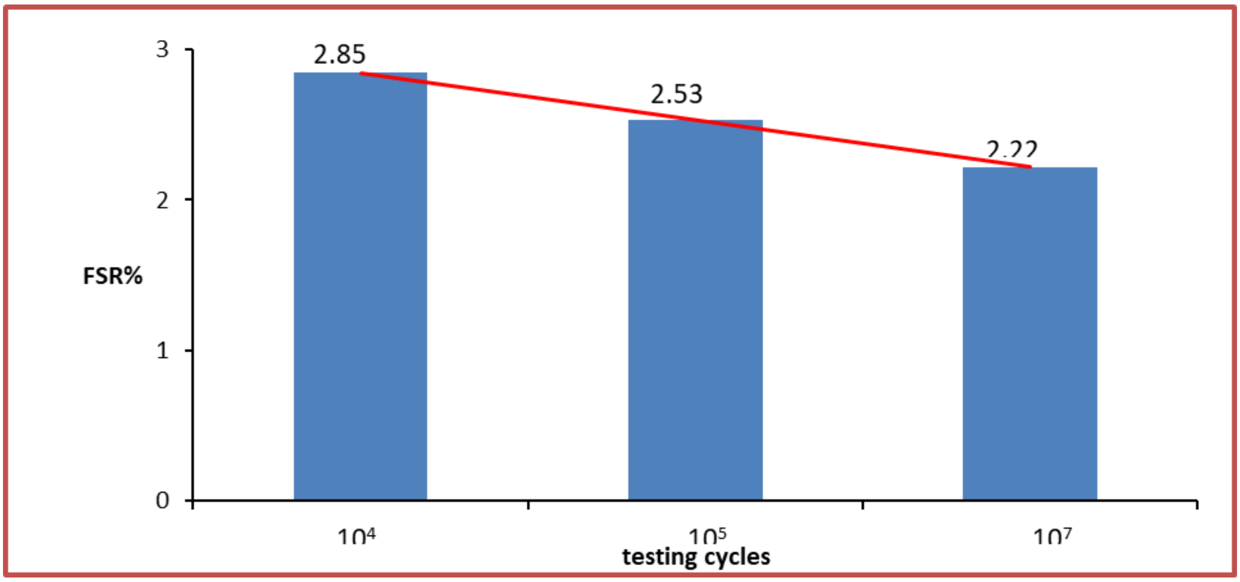

Figure (7) Variation of FSR% against testing life

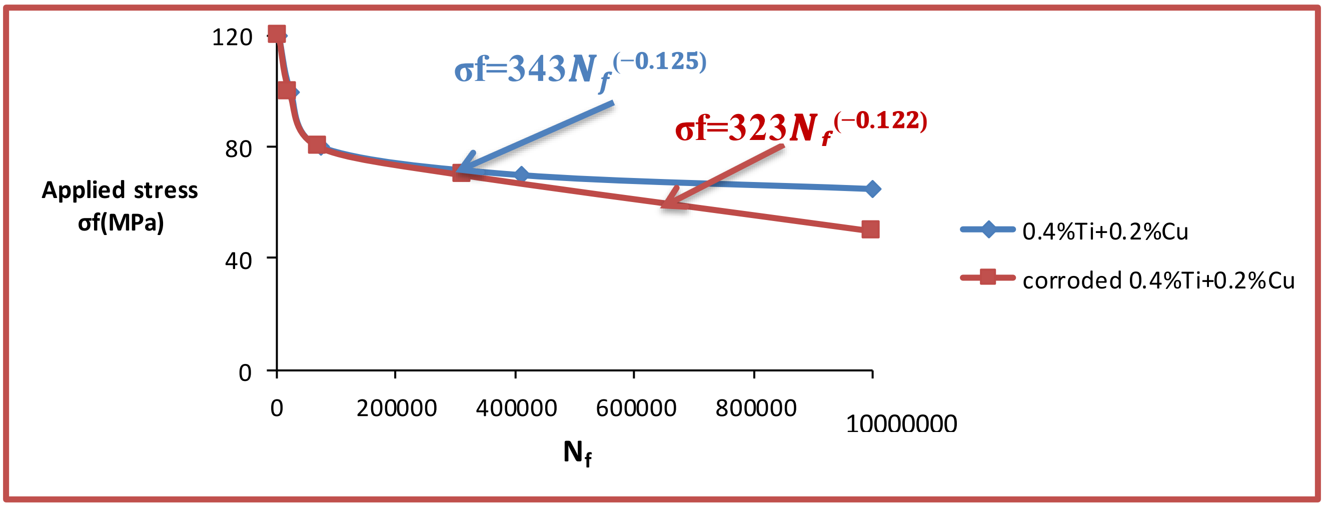

Figure (8) S-N curves for AA6061 metal matrix with nano material

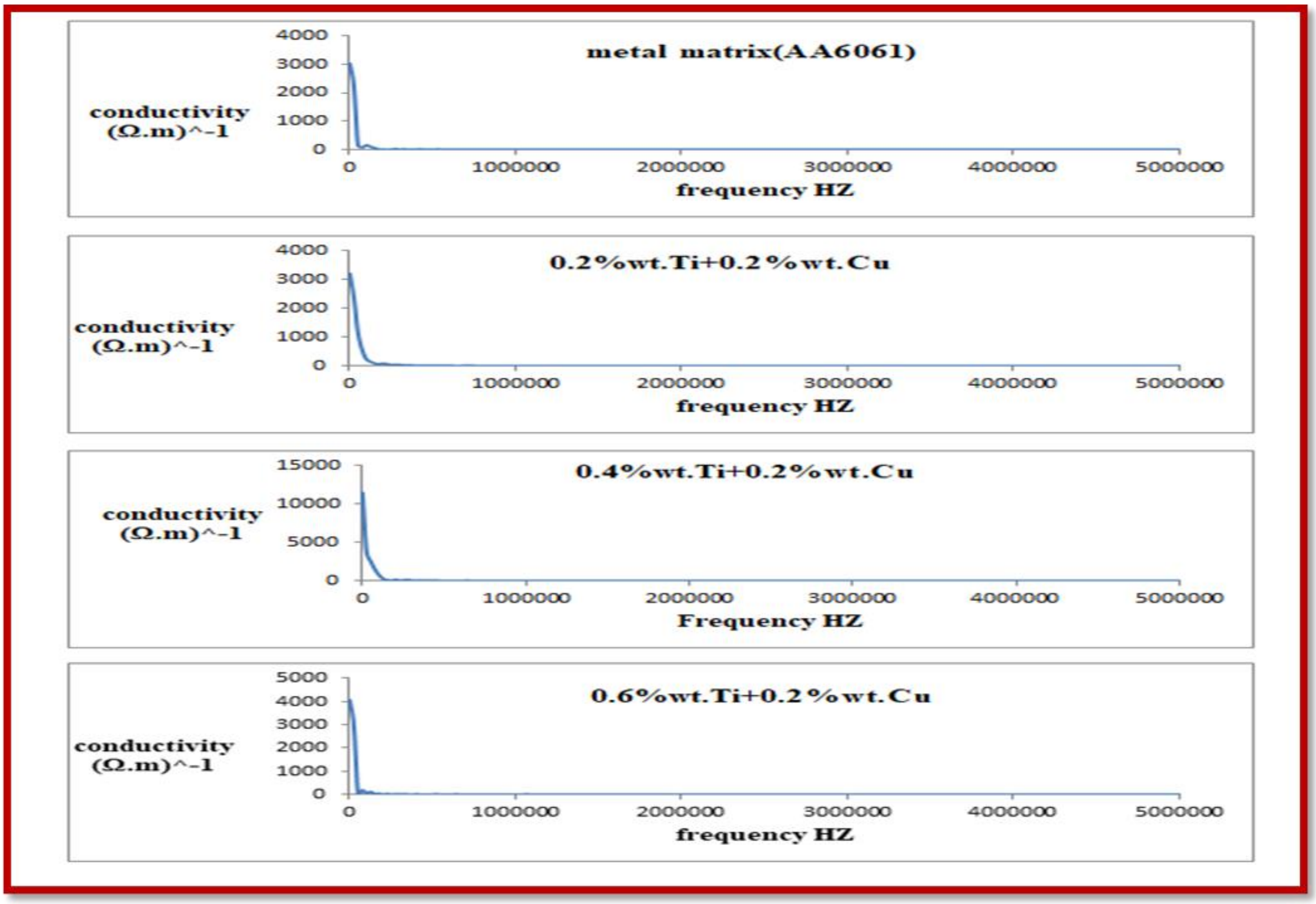

Figure (9) shows the electrical conductivity of hybrids nano composite/AA6061

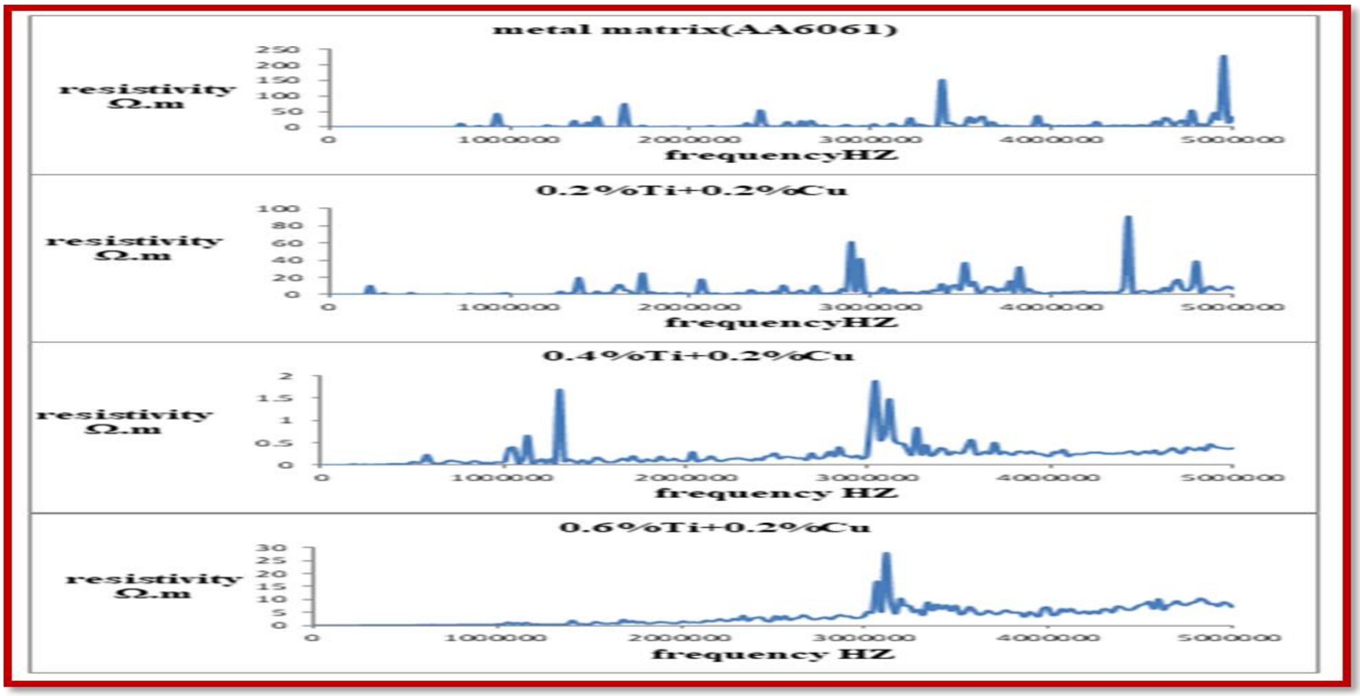

Figure (10) Resistivity with nano material and without nano material

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