# An Estimation Study on Fatigue transition Life of Nanocomposites Reinforced by $AL_2O_3$

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## Abstract:-

The behaviors of 2024Al/$Al_2O_3$ nanocomposite which wes fabricated by stir casting at 450r.p.m and casting temperature of $850^0$C have been examined under four points loading of rotating bending. fatigue test at room temperature (RT), humidity of 40% and fully revers stress ratio (R=-1).The trend of the fatigue properties obtained from the experimental tests showed an improvement in the fatigue strength and life compared to the metal matrix 2024Al alloy. The S-N curves were obtained and the equations of the nanocomposite which described the constant S-N curves were established based on Basquin power law equation for 0.2, 0.4, 0.6, 0.8 and 1.0wt. % $Al_2O_3$. The experimental results analysis revealed that the fatigue strength of nanocomposite are improved by 0.53%, and the fatigue transition life is increased by 16.02 % compared to the metal matrix.

**Keywords: - 2024Al/$Al_2O_3$ nanocomposite , nanoparticles , $Al_2O_3$ ,constant fatigue test .**

## Introduction

Nowadays, the metal matrix nano composites (MMCs) were used in different field of industries due to good mechanical and fatigue resistance ,These better properties make the MMCs attractive for various applications in automobile , military industries and aerospace [1]. The manufacturing methods of MMCs are powder metallurgy, stir casting and ultrasonic casting etc. [2].

Four points bending fatigue test of Barium titan ate $BaTiO_3$-$Al_2O_3$ nano composites were carried out at stress ratio R=0.1 and 20 Hz frequency. It was found that the fatigue behaviors of the above composite exhibited high fatigue resistance compared to monolithic $Al_2O_3$.[ 3 ].

Sung-po et al [4] examined the three point bending fatigue of $Al_2O_3$/SiC composite .They found that the $Al_2O_3$ / SiC has good ability for retardation the cracks ad resulting high fatigue strength and lives

R.Senthilkumar et al (2015) [ 5 ] examined fatigue behaviors of the Micro and nanocomposites for 2014Al alloy as a matrix with $Al_2O_3$ reinforced material .It was revaled that the fatigue properties are improved due to enhancement of the mechanical properties of the composites .

Friction stir processing (FSP) method was used to prepare the 5052Al-$Al_3Ti$ nanoparticles with different size of $Al_3Ti$.It was attained that the FSP increased the fatigue endurance limit at $10^7$ cycles by 28% and 32% compared to the annealed specimen under 2 and 3.5 vol. % of nanomaterial respectively [ 6 ].

It is observed experimentally that the MMCs have greater mechanical fatigue properties compared to the as cast metal .This finding play good role in enhancement the fatigue properties [ 7 ].

Metal matrix composite (Al-SiC) of 50 nanometers size of particles were fabricated for different vol . % of SiC in order to find the optimum fatigue improvement .It was found that the ductile fracture increased when the vol .% of reinforced material increased .[ 8 ].

50 nanometers reinforcement particles size of 10 wt. % were used to fabricated the nanocomposites based metal matrix 6061Al alloy .The composite and as cast metal 6061 Al alloy were tested under constant and cumulative fatigue in order to obtain the percentage of enhancement in the

fatigue life and strength .It was found that the fatigue strength of the composite is improved by 12.8% while the cumulative fatigue life is enhanced by 39.38% and 33.37% for high – low and low – high loading sequence respectively . [9]

## Experimental work

### Material

In this work aluminum alloy 2024 has been used as metal matrixfor nanocomposites and that the chemical composition is given as shown in **Table. 1**.

The present work focus to determine the fatigue properties of 2024Al/$Al_2O_3$ nanocomposites for different wt. % of $Al_2O_3$ under room temperature and stress ratio R= -1.

**Table .1 the chemical composition of matrix metal**

| Metal | Si wt. % | Fe Wt. % | Cu Wt. % | Mn Wt. % | Mg Wt. % | Cr Wt. % | Zn Wt. % | Ti Wt. % | Others total Wt. % |
|---|---|---|---|---|---|---|---|---|---|
| **2024Al alloy Standard [10]** | 0.5 | 0.5 | 3.8-4.9 | 0.3-0.9 | 1.2-1.8 | 0.1 | 0.25 | 0.15 | 0.15 |
| **2024Al-alloy experimental** | 0.48 | 0.46 | 4.2 | 0.52 | 1.48 | 0.08 | 0.21 | 0.11 | -- |

The reinforcement material was chosen of high hardness and mechanical properties [10].This material is $Al_2O_3$ of chemical. composite wt% illustrated in **Table .2** With biggest radius less 10 nanometers

Table .2 chemical composition of $Al_2O_3$ reinforcement material [11].

| Element | $TiO_2$ | $Fe_2O_3$ | CaO | Others | Alumina (α) |
|---|---|---|---|---|---|
| Wt.% | 1.8 | 0.8 | 1.1 | 0.02 | 93 |

## Experimental procedure

The Aluminum 2024 alloy metal matrix reinforced with various amount of wt. %$Al_2O_3$ (0.2, 0.4, 0.6, 0.8 and 1.0) wt. %$Al_2O_3$ have been fabricated using stir casting technique. The test rig which used to manufacture the nano composites is given elsewhere [12].

The fatigue tests were conducted with rotating bending testing machine (UBM) given in **Fig. 1.**

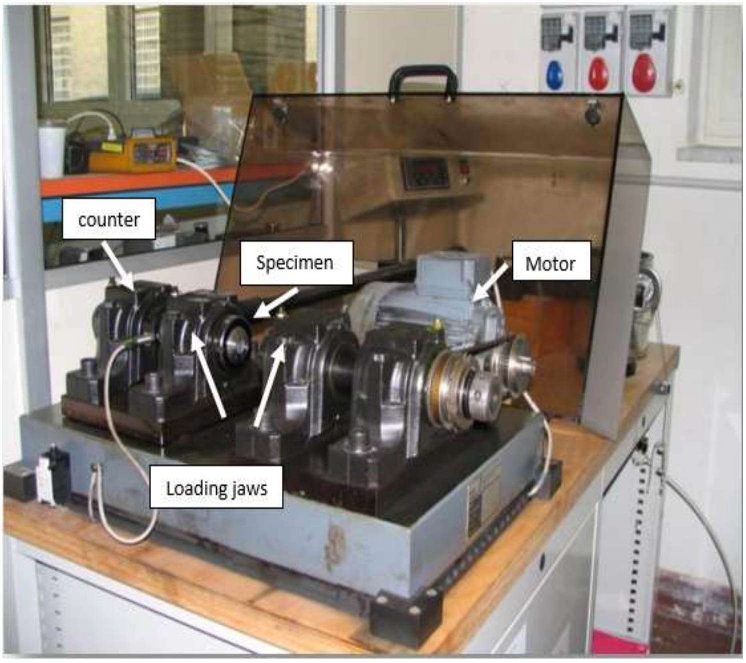


Fig .1 fatigue test machine

## Specimen preparation

The material of the specimens was received as 15mm in diameter and 150mm in length from the cast moulds. The outer profile of the specimens was then machined using CNC lathe, the fatigue specimen is shown in **Fig. 2** according to ISO 1143-2010[13].

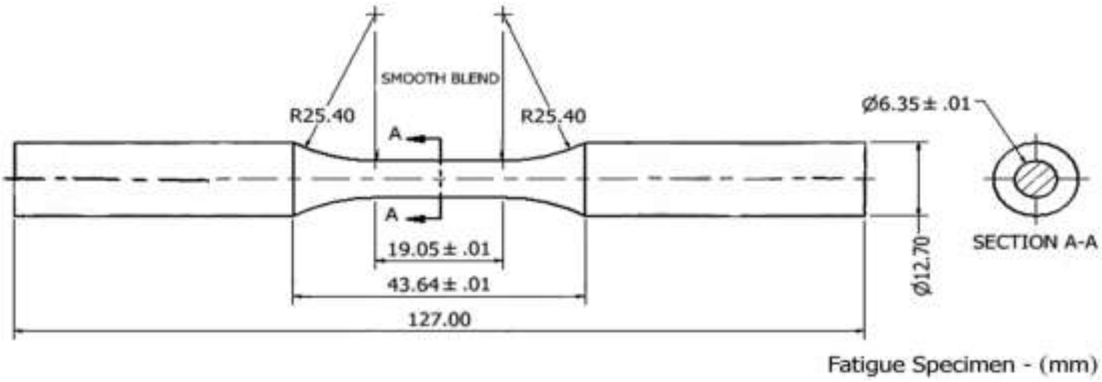


**Fig. 2 fatigue specimen**

The fatigue tests were down with the following specifications :

Type of test: four points bending.

Room temperature: $24^0$C .

Relative humidity: 40% .

Testing frequency: 60Hz .

Stress ratio R=-1

## Result and Discussion

The mechanical properties of 2024 Al alloy metal matrix and the 2024Al/$Al_2O_3$ composite with different amount of Alumina obtained from Reference [13] shown in **Table. 3.**

Table .3 Mechanical properties 2024 Al an the 2024Al/$Al_2O_3$ nanocomposites [13]

| Material Specimen series No. | | | U.T.S. (MPa) | Y.S. 0.2% offset (MPa) | Elongation ( % ) | $AL_2O_3$ wt.% |
|---|---|---|---|---|---|---|
| **Cast Al** | 1 | | 177.9 | 83 | 10.5 | 0 |
| **Al/$AL_2O_3$ ($MMC_s$)** | 2 | | 184.6 | 89 | 9.3 | 0.2 |
| **Al/$AL_2O_3$ ($MMC_s$)** | 3 | | 210.1 | 101 | 7.8 | 0.4 |
| **Al/$AL_2O_3$ ($MMC_s$)** | 4 | | 184.4 | 89 | 9.4 | 0.6 |
| **Al/$AL_2O_3$ ($MMC_s$)** | 5 | | 182.6 | 85 | 9.6 | 0.8 |
| **Al/$AL_2O_3$ ($MMC_s$)** | 6 | | 180.7 | 84 | 9.8 | 1.0 |

## S-N Curves

The constant S-N experimental results of six groups ; 2024 Al as cast (series 1), 0.2wt% $Al_2O_3$ ( series 2), 0.4 wt.% $Al_2O_3$(series 3), 0.6 wt.% $Al_2O_3$(series 4), 0.8 wt.% $Al_2O_3$( series 5) and 1 wt.% of $Al_2O_3$ ( series 6) composites are given in **Table .4 .**

**Table .4 Experimental S-N curves of six groups of testing**

| No. of series | Material 2024 $Al/Al_2O_3$ | Applied Stress (MPa) | No. of cycles to failure | Average no. of cycles |
|---|---|---|---|---|
| $1a,1a^{-},1a^{--},1a^{---}$ | 2024 Al alloy Metal Matrix | 150 | 64 , 66 ,65,62 | 64 |
| $1b,1b^{-},1b^{--},1b^{---}$ | | 125 | 11985 , 11833 , 11864,10019 | 11425 |
| $1c,1c^{-},1c^{--},1c^{---}$ | | 100 | 7014065 , 6964231 , 6977121,6413160 | 6842144 |
| $1d,1d^{-},1d^{--},1d^{---}$ | | 90 | 142939642 , 141758922 , 140565777,139611832 | 141219043 |
| $2a,2a^{-},2a^{--},2a^{---}$ | 0.2 wt. % $Al_2O_3$ Composite | 150 | 67 , 68 , 67,70 | 68 |
| $2b,2b^{-},2b^{--},2b^{---}$ | | 125 | 12370 , 12433 , 12357,13017 | 12544 |
| $2c,2c^{-},2c^{--},2c^{---}$ | | 100 | 7264539 , 7299470 , 7278614,8641211 | 7621033 |
| $2d,2d^{-},2d^{--},2d^{---}$ | | 90 | 147415880 , 147703982 , 148786413,150983201 | 148722369 |
| $3a,3a^{-},3a^{--},3a^{---}$ | 0.4 wt. % $Al_2O_3$ Composite | 150 | 71 , 72 , 71,75 | 72 |

| | | | | |
|---|---|---|---|---|
| **3b,3b$^{-}$,3b$^{--}$,3b$^{---}$** | | 125 | 12964 , 13121 , 12928,15631 | 13661 |
| **3c,3c$^{-}$,3c$^{--}$,3c$^{---}$** | | 100 | 7578833 , 7613801 , 7599827,9812714 | 8151293 |
| **3d,3d$^{-}$,3d$^{--}$,3d$^{---}$** | | 90 | 154453876 , 155586729 , 155923411,160721921 | 156671484 |
| **4a,4a$^{-}$,4a$^{--}$,4a$^{---}$** | **0.6 wt. % $Al_2O_3$ Composite** | 150 | 67 , 67 , 66 , 69 | 67 |
| **4b,4b$^{-}$,4b$^{--}$,4b$^{---}$** | | 125 | 12357 , 12355 , 12463,14911 | 13021 |
| **4c,4c$^{-}$,4c$^{--}$,4c$^{---}$** | | 100 | 7261750 , 7275515 , 7309681 , 9641311 | 7872064 |
| **4d,4d$^{-}$,4d$^{--}$,4d$^{---}$** | | 90 | 148070511 , 149281667 , 149976829,155641433 | 115723285 |
| **5a,5a$^{-}$,5a$^{--}$,5a$^{---}$** | **0.8 wt. % $Al_2O_3$ Composite .** | 150 | 66 , 65 , 66 , 69 | 66 |
| **5b,5b$^{-}$,5b$^{--}$,5b$^{---}$** | | 125 | 12250 , 12190 , 12301,14011 | 12688 |
| **5c,5c$^{-}$,5c$^{--}$,5c$^{---}$** | | 100 | 7111321 , 7083621 , 7209171 , 7301816 | 7176482 |

| | | | | |
|---|---|---|---|---|
| **5d,5d$^{-}$,5d$^{--}$,5d$^{---}$** | | 90 | 147370681 , 148211417 , 145321989 , 146776439 | 146776439 |
| **6a,6a$^{-}$,6a$^{--}$,6a$^{---}$** | **1.0 Wt. % $Al_2O_3$ Composite** | 150 | 65 , 64 , 65,68 | 65 |
| **6b,6b, 6b$^{--}$,6b$^{---}$** | | 125 | 12136 , 12011 , 11988 , 13711 | 12641 |
| **6c,6c$^{-}$, 6c$^{--}$,6c$^{---}$** | | 100 | 7008131 , 6897527 , 6876714, 7011832 | 6948551 |
| **6d,6d$^{-}$, 6d$^{--}$,6d$^{---}$** | | 90 | 143279161 , 139417989 , 140829171 , 142791621 | 141579485 |

96 specimens were tested at room temperature and stress ratio R= -1. The results have been performed at as cast 2024 Al-alloy and various reinforcements of $Al_2O_3$ and graphically plotted in the form of S-N curves which are presented in **Fig .3.**

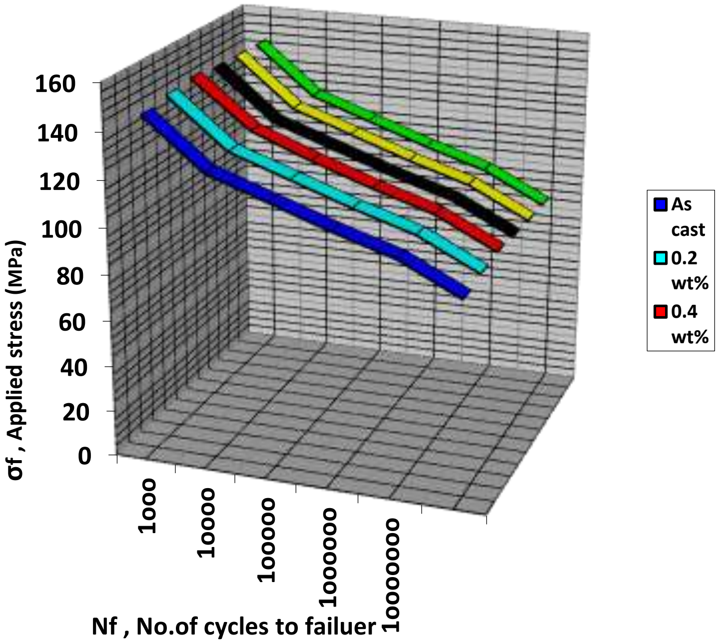


**Fig.3 Experimental results S-N curves for metal matrix and five different nanocomposite .**

The equation of power law regression is given by [14].

$$\sigma_f = A\, N_f^b \qquad \text{.........(1)}$$

Where ( $\sigma_f$ )is the applied stress to failure.

($N_f$ )is the number of cycles to failure.

A and b are material constants which are the fitting parameters of the above equation

The fatigue parameters and strength for the above six groups can be illustrated in **Table .5.**

**Table .5 S-N equations with calculated fatigue parameters for various wt. % $Al_2O_3$ nanoparticles**

| No. series | Wt. % $Al_2O_3$ | A | b | Equation $\sigma_f = A N_f^b$ | Stress at $10^7$ and $5*10^8$ cycle | Impro. in σe | ($R^2$) | $\sigma_{fs}$ , fatigue strength at trasition life ($10^4$cycle) |
|---|---|---|---|---|---|---|---|---|
| 1 | As cast | 173.4 | -0.0349 | $\sigma_f = 173.4\ N_f^{-0.0349}$ | 98.798<br>86.189 | ----<br>---- | 0.98 | **125.732 MPa** |
| 2 | 0.2 | 173.86 | -0.0349 | $\sigma_f = 173.86\ N_f^{-0.0349}$ | 99.06<br>86.418 | 0.27 %<br>0.265% | 0.98 | **126.066 MPa** |
| 3 | 0.4 | 174.3 | -0.0349 | $= 174.3\ N_f^{-0.0349} \sigma_f$ | 99.31<br>86.636 | 0.53%<br>0.518% | 0.98 | **126.385 MPa** |
| 4 | 0.6 | 174.43 | -0.035 | $\sigma f = 174.43\ Nf^{-0.035}$ | 99.22<br>86.528 | 0.44 %<br>0.393% | 0.98 | **126.363 MPa** |
| 5 | 0.8 | 173.78 | -0.0349 | $\sigma f = 173.7\ Nf^{-0.0349}$ | 99.01<br>86.338 | 0.24 %<br>0.172% | 0.98 | **125.95 MPa** |
| 6 | 1.0 | 173.78 | -0.035 | $\sigma f = 173.78\ Nf^{0.035}$ | 98.85<br>86.205 | 0.07 %<br>0.018% | 0.98 | **125.892 MPa** |

Fatigue test showed a significant improved in fatigue strength in all composite investigated. The as cast alloy represents lower fatigue strength than the composite. The highest enhancement in fatigue strength was observed at 0.4wt %$Al_2O_3$ as 0.53% and 0.518% for $10^7$and $5*10^8$ cycles respectively [ 15 ] [ 16 ].The lowest enhancement was occurred at 1.0 wt. % $Al_2O_3$ compared to the as cast 2024Al alloy .Akio et al [17] examined the nanocomposite specimen under constant fatigue test and they conclude that the nanomaterial play good role in improvement fatigue of Al alloys. Alalkawi et al [9] found that the endurance fatigue limit at $10^7$ cycles is enhanced due to addition of 10 wt. % $Al_2O_3$ to the 6061 Al alloy. This improvement was 12.28% i.e., the fatigue strength of as cast was 87.3 MPa raised to 99.53 MPa for the nanocomposite

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### Fatigue life and nanomaterial ($Al_2O_3$)

For high cycle fatigue (HCF) regein, the number of cycles required to produce fatigue is higher than $10^4$ up to $10^7$ sometimes to $5*10^8$ cycles for non-ferrous metals .While the low cycle fatigue (LCF) region defined as that the fatigue failure happens after a relatively small number of cycles . Fatigue failures for component of less than $10^4$ cycles are considered to be low – cycle fatigue failure [19]. In this section, the improvement of fatigue transition life due to adding various wt. % of $Al_2O_3$ will discussed . **Table .6** gives the transition life between LCF and HCF regions for the composite based on the metal matrix 2024Al alloy.

**Table .6 Transition life improvement percentage**.

| As cast | 0.2 wt. % $Al_2O_3$ | 0.4 wt. % $Al_2O_3$ | 0.6 wt. % $Al_2O_3$ | 0.8 wt. % $Al_2O_3$ | 1.0 wt. % $Al_2O_3$ |
|---|---|---|---|---|---|

| Series 1 | Series 2 | Series 3 | Series 4 | Series 5 | Series 6 |
|---|---|---|---|---|---|
| **$10^4$** | 10791 | 11602 | 11539 | 10510 | 10371 |
| **Improvement percentage (IP)** | | | | | |
| ----- | 7.91 | 16.02 | 15.39 | 5.1 | 3.71 |

The above calculation based on fatigue stress $\sigma_f$ =125.732 MPa corresponding to $10^4$ cycles for metal matrix 2024 Al alloy. **Fig. 4** shows the IP against the different amount of wt. % $Al_2O_3$.

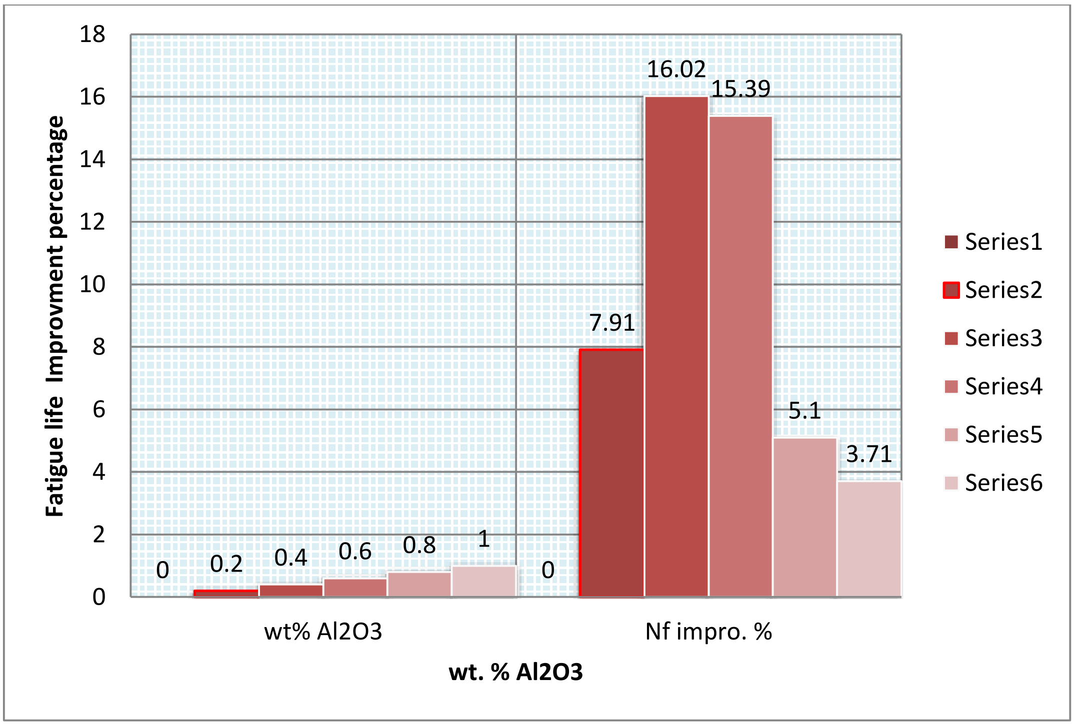


**Fig. 4 Improvement percentage in the fatigue life (transition life) due to adding $Al_2O_3$ nanoparticles.**

It is clear that the fatigue transition life enhanced and the maximum enhancement occurred at 0.4 wt. % $Al_2O_3$ but all the percentage amount of $Al_2O_3$ added improved the transition life in comparison with the based metal matrix alloy. These improvements may be coming from the following:

1- The high Ultimate stress, Yield stress and Hardness of the reinforced particles itself lead to improved fatigue transition life and strength [20].
2- Good dispersion of $Al_2O_3$ in the nanocomposite works to improve the mechanical and fatigue characterization leading to enhance fatigue transition life [21].
3- The homogeneousity of reinforcement particles and little porosity leads to raise the strength and life of composites [22].
4- High bounding between metal matrix and $Al_2O_3$ made the composite of high mechanical properties and substance the applied load greater than the metal matrix which give long fatigue life compared to the metal matrix [23].

**Conclusion**

This section lists the major conclusion to be drawn from the current research

1. The purpose of application the nano $Al_2O_3$ was aimed at maximizing the mechanical characterizations and fatigue life.
2. Experimentel analysis indicated that fatigue strength or fatigue endurance limit at $10^7$ and $5*10^8$ improve with the increase in wt.% of $Al_2O_3$. But the maximum endurance limit

is occurred at 0.4wt% $Al_2O_3$ composite.

3. The fatigue transition lives of all the composites were enhanced compoared to the metal matrix. The maximum improvement is observed in composite including 0.4wt% $Al_2O_3$ by 16.02% improvement percentage (IP).
4. The fatigue transition lives of all the composites were increased by the following improvement percentage ,7.19, 16.02, 15.39, 5.1 and 3.71 crossponding to (0.2, 0.4, 0.6, 0.8 and 1)wt% $Al_2O_3$.

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# دراسة تقيمية لعمر الكلال الانتقالي للمركبات النانوية المقواة بأوكسيد الالمنيوم

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**الخلاصة:-**

تم فحص سلوك الكلال للمركبات النانوية عند التحميل الرباعي الدوار في درجة حرارة الغرفة وعند رطوبة 40% ونسبة اجهاد -1 ، تم اضافة المادة النانوية الى سبيكة الالمنيوم 2024 وذلك بطريقة السبك بالتحريك عند 450 دورة في الدقيقة ودرجة حرارة 850 درجة مئوية و بنسب وزنية 0.2% ،0.4 % ، 0.6 %، 0.8 % و 1.0% . اظهرت النتائج العملية تحسن في مسار الخواص ( منحنى الاجهاد عدد الدورات ) و معادلاته اعتماد على معادلة باسكوين. تحليل الاختبارات العملية اوضح تحسن مقاومة الكلال بنسبة 0.53% ، وعمر الكلال الانتقالي قد ازداد بنسبة 16.02 % مقارنة مع المعدن الاساس .

**الكلمات المفتاحية:- الحبيبات النانوية، فحوصات الكلال الثابتة .$2024Al/Al_2O_3$ المركبات النانوية $Al_2O_3$** ,