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Study of Dust Effect in Winds of Sistan Region, Iran, on Decreased Performance and Lifetime of $AlCu_4Mgl$ Alloy

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Abstract: In this study, effects of the dust exist in the winds blowing in Sistan region on lifetime $AlCu_4Mg1$ aluminium alloy are discussed. This alloy can be used in manufacturing blades of a low-power wind turbine. In collision with this alloy and the resulted impact this dust can and corrode their surface and cause an early erosion. Here, the goal is to study the effects of the impact resulted from dust particles collision on the lifetime of this alloy. This research has been done as two stages of experimental study. In the first stage, a setup is designed and manufactured that simulates the condition of high-speed winds like that blows in the study region, together with the related dust. These conditions have been imposed on the lab samples made of aluminium alloy. In the next stage, these samples are put into a fatigue testing machine and while imposing stress, lifetime rate of the samples is calculated. Then, by Analysis of Variance Method, decreased rate of the lifetime of the sample is numerically calculated according to the conditions existing in Sistan region and compared with the lab results. Numerical results have a good agreement with the experimental results. The most decrease in the lifetime caused by the dust in the winds blowing in Sistan region has been 8.5% which given high potential of wind blowing in this area, strengthens the incentive to build a wind farm in Sistan region.

Key words: Dust, wind turbine, $AlCu_4Mgl$ aluminium alloy, lifetime, region

INTRODUCTION

Sistan region has long been one of the windiest regions in Iran. According to statistical investigation made in Zabol station, annual average of wind speed in this station is 5.4 and 7.1 m sec^{-1} in Loutak station 35 km far from Zabol. The maximum wind speed recorded in this station in July is 28 m sec^{-1}.

Wang *et al*. (2011) studied on determining multi-axial fatigue for 2024-T4 aluminium alloy. Arranging experiment tables including number of sample and geometrical specifications of the sample under survey and the conditions of strain and stress in different points of the sample they drew axial stress-lifetime, axial strain-lifetime diagrams, etc. Another research was carried out by Gonowski in Opole University to determine fatigue lifetime of $AlCu_4Mg1$ aluminium alloy. They put >150 lab samples under net bending load, net torsional load, a combination of bending and torsional loading conditions in In-and-Out Phase conditions and finally, drew diagrams of lifetime-based changed stress for any case. A study was given by Sielski (2007) concerning reviewing all necessary issues on aluminium structure. This study includes such sections as material characteristics and behaviour of aluminium; details of structure; design of aluminium structure; design and analysis of aluminium fatigue; residual stress, distortion in aluminium, etc. and some diagrams according to the cycle and changed stress under special conditions.

Zengliang (2001) investigated into multi-axial fatigue of 2024-T4 aluminium alloy. In this study, they provided some interesting diagrams depending on changed cycle and stress and strain for different loading conditions including completely non-axial transverse loading, completely torsional transverse loading, axial torsional loading, etc. Piprani and Samal (2003) studied an extensive research on determining fatigue life of the aluminium alloy sample including some parts such as the lifetime under conditions of hard working, corrosion, fatigue test, stress calculations under special conditions, etc. Khosravi (2010) conducted a study titled “An Investigation into Vertical Distribution of Dust Caused by Storm in the Middle East Using NAAPS Model (Case Study: Sistan Region, Iran)”. In this research, he provided an standard (criterion) for the dust content of the air when a storm blows in milligram of dust per cubic meter of mix during some months of year. The another work under the title of “Study of Effects of Dust on the Performance of Wind Turbine” was performed by Khalfallah and Koliub (2007) in Egypt on an actual sample of wind turbine during a 9 month study period with different conditions. In this study, effect of high roughness of the blade resulted from dust packing, on performance periods of the wind turbine and effect of

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changed area of blade surfaces covered with dust all examined in that study. Another study under the title of dust effect on the performance of wind turbine airfoils was carried out by Ren and Ou (2009). In this research, two-dimensional solution of Navier-Stokes equations and turbulence model to study incompressible viscous fluid passing through two-dimensional airfoil of wind turbine under clean surface conditions and rough surface has been examined as well. A numerical simulation for the airfoil has been carried under clean conditions and the changes in drag coefficient and lift coefficient in different heights of roughness have been measured.

In this study, aluminum alloy has been used and effects of the dust existing in Sistan region on its lifetime have been investigated. Since, design and manufacture of a wind turbine well adapted for the conditions of Sistan region is not unexpected this alloy can be used in manufacturing wind turbines well adapted for the conditions of this region in small sizes for such uses as drawing water from well for agricultural purposes. Meanwhile since modulus of elasticity of this alloy is very close to the composite sample used in large-size wind turbines installed in Sistan region and the parameter of surface effects has been also studied here, the results from this study can be generalized to 660 kW wind turbine installed in Sistan region.

DESIGN OF THE SETUP AND METHODOLOGY OF EXPERIMENTS

General schema of the setup as shown in Fig. 1 has been designed and manufactured for implementation the first stage of experiments to be effect of dust on the sample. After first stage, the relevant sample was opened and put into the fatigue tester machine. The designed setup consists of an axial fan, the sample under survey,anemometer, dust reservoir, convergent nozzle three phase MCB (miniature circuit breaker) strain gage together with special glue, multi meter, resistor and workbench.

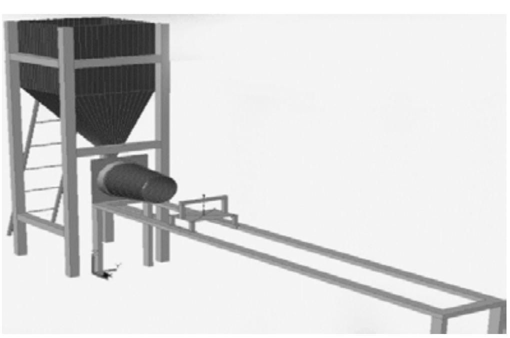

Fig. 1: The setup designed for simulating the conditions of wind storms along with dust

To create wind with desired speed an industrial blower fan with a three-phase motor, blade diameter of 40 cm, 2800 rpm, equipped with a 0.75 kW electromotor, with a capacity of 6000 m^3/h was used (Tabatabei, 2007) which nominalspeed output from it was 13.26 m sec^{-1}. To adjust wind speed, the convergent nozzle was used. The nozzle was designed in conical form to achieve the speed of 27 m sec^{-1} in the outlet port.

The dust reservoir is designed for feeding soil to the wind flow and simulating the storms blowing in Sistan region. The result of xrd (x-ray diffraction) analysis made on the dust of this area shows that it is principally made of clay and various compounds of quartz called feldspar. because of adhesion nature (properties) of the dust and overcoming concentric forces among particles, the shape of a non-centric funnel was used. Also, the non-centric funnel allows the dust feeding port to place exactly behind the fan and the place where the air is suctioned. This will in turn causes the air-dust mix to become more uniform and homogeneous.

In addition, the xrd analysis has indicated that 7.9% of the sample contents particles with diameter of about 4750 μm, almost equal to 4.7 mm. For critical conditions, despite its low percentage in the sample, the diameter of 5000 μm equal to 5 cm has been considered as the basis for calculations.

During the experiments, we put a strain gage on the thinnest part of the sample. This strain gage in a wheatstone bridge together with another strain gage and two isotropic resistors are responsible for showing the strain imposed on the sample due to imposing the force from the impact of the wind full of dust. The imposed strain rate due to the collision of the particles to the sample is assessed depending on changed voltage of the two ends of wheatstone bridge and the measurement factor as a part of the characteristics of the strain gage.

Given the methods of planning and analysis of examinations (DOE), the examinations are planned. First, the sample is put in the designed setup (Fig. 1). At the same time when the fan is turned on, feeding of the dust is started. The nozzle has been already put in the place for regulation of wind speed. The sample under survey is put along with the strain gage in the place. At the end of the examination time at the first stage, the sample is removed from the setup and put in the fatigue tester machine. In this stage, the constant load imposed on all of the samples is selected 25 kgf equal to 245 N. This force imposes a strain equal to 578 MP on the sample (Shokoufeh Far, 2004).

ANALYSIS OF VARIANCE FOR THE RESULTS OBTAINED FROM EXPERIMENTS

Given the results obtained from implementation the first and second stages of the examinations, analysis of variance has been carried out numerically to find the lifetime under *in vitro* conditions of region and the conditions rather than that of experiments.

To carry out the analysis of variance, the power function as $y' = (y+k)^{\lambda}$ $y' = (y+k)^{\lambda}$ is used. Now, for each category of speeds, a separate diagram can be drawn and thereby the lifetime may be calculated under desired conditions. The lifetime rate in them are specified for the examined conditions. Also, under the conditions of the winds blowing along with real dust in this region that is wind speed of 7 m sec^{-1} and volume fraction of 5%, the lifetime rate is observed.

As observed in Fig. 2, for the speed of 18.5 m sec^{-1}, the lifetime is 1531 rpm. However, from the results obtained from the experiments, this amount is 1538 rpm, whose error for the selected defaults in the software and its analyzer function is equal to 0.4%. For the speed of 11 m sec^{-1}, the number shown by the diagram is 1666 rpm and its real amount is 1263 rpm, whose error is equal to 31%. For the speed of 5 m sec^{-1}, the diagram shows 1689 rpm while its real number is 1574 rpm with an error of 7%.

As seen in Fig. 3, the lifetime can be seen with different rates under *in vitro* conditions analyzed. Also,

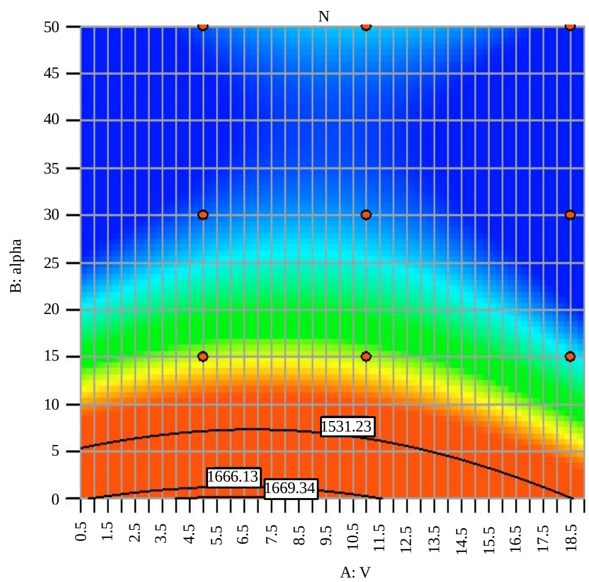

Fig. 2: Analysis of variance and lifetime diagram under clean condition (the control samples)

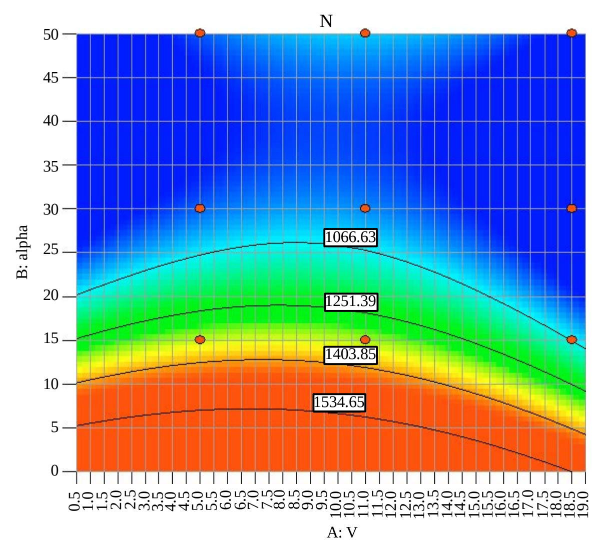

Fig. 3: Analysis of variance and lifetime diagram with speed of 18.5 m sec^{-1} in different volume fractions

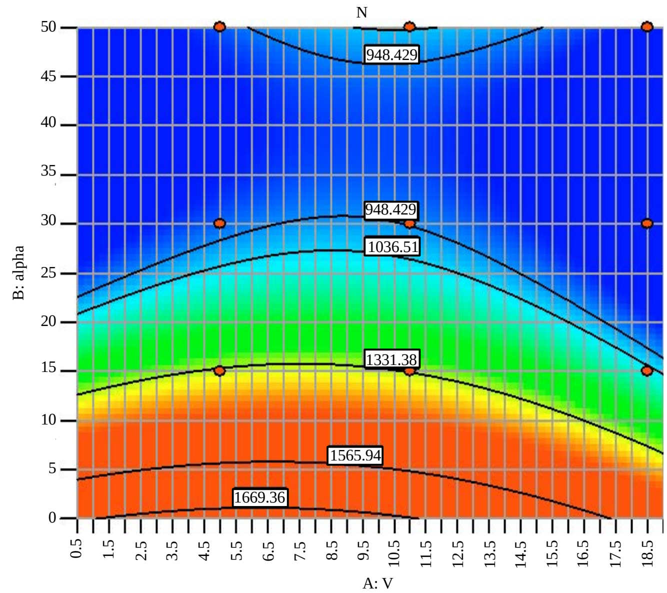

Fig. 4: Analysis of variance and lifetime diagram with speed of 11 m sec^{-1} in different volume fractions

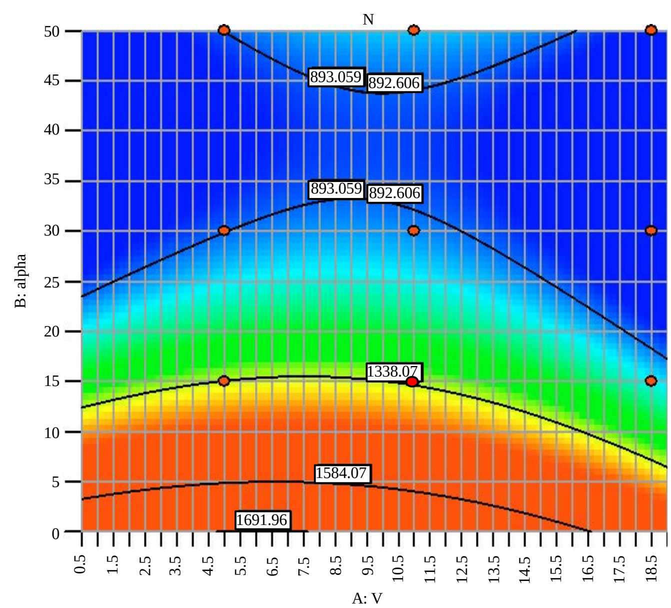

Fig. 5: Analysis of variance and lifetime diagram with speed 5 m sec^{-1} in different volume fractions

under the conditions of real volume fraction, 5% of the dust proved to have a lifetime equal to 1403 cycles while the control sample that is influenced by clean air flow has a lifetime equal to 1534 cycles. As a result, it can be concluded that decreased lifetime of the sample under the conditions in which wind speed is 18.5 m sec^{-1} with real dust will be equal to 8.5%. However, if the dust of the region exceeds from this amount and reaches 10% this decrease in the lifetime will be 18% and if we increase further the dust in the region until we reach volume fraction of 15%, the decreased lifetime will be 30%.

Figure 4 shows lifetime rates with the speed of 11 m sec^{-1} and different volume fractions. The lifetime rate for the control sample is 1669 cycles. Under real conditions, e.g., volume fraction of 5%, the lifetime will be 1566 cycles with a decrease in the lifetime reaching 6%. In volume fraction of 15%, the lifetime rate is 1331 cycles, with a decrease in the lifetime equal to 20%. Also in volume fraction of 30%, the lifetime rate is 948 cycles with a decrease of the lifetime equal to 43%.

Figure 5 shows lifetime rates with the speed of 5 m sec^{-1} and different volume fractions. The lifetime

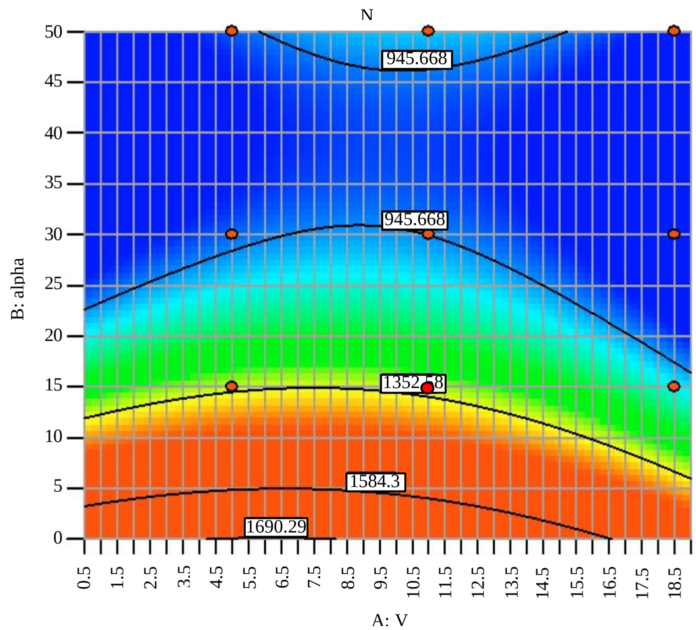

Fig. 6: Analysis of variance and lifetime diagram with speed 7 m sec^{-1} in different volume fractions

rate for the control sample is 1691 cycles. Under real conditions, e.g., volume fraction of 5%, the lifetime will be 1584 cycles with a decrease in the lifetime reaching 6%. In volume fraction of 15%, the lifetime rate is 1338 cycles with a decrease in the lifetime equal to 21%. Also, in volume fraction of 30%, the lifetime rate is 893 cycles with a decrease of the lifetime equal to 47%.

Figure 6 shows the lifetime rates under real conditions of the region wind that is 7 m sec^{-1} in different volume fractions. If we assume that there is no dust in the region winds and we have a so called clean air flow, the lifetime of the sampleis equal to 1690 cycles.

But as the volume fraction of the particles increases to 5%, the lifetime reaches 1584 cycles with a decrease in the lifetime relative to that of clean air flow is 6%. As the volume fraction of the particles increases to 15%, the lifetime reaches 1352 cycles with a decrease in the lifetime equal to 20%. With the volume fraction of 30%, the lifetime is shown to be 945 cycles, with a decrease in the lifetime equal to 44%.

ANALYSIS OF UNCERTAINTY

Given the details as mentioned in the instruction manual, the existing errors and uncertainty in calculating the parameters include:

- What the strain gages were sensitive to was the temperature under survey affecting the resulted number. Calibration diagram of the strain gage is as follows and given the environment temperatures during the experiments ranging from 16-24°C, the apparent strain shown by the strain gage matches real strain
- Strain gage resistance is equal to 120±0.3 Ω. This tolerance causes an error in the whole research and designs because the amount of V_g in the initial case should be zero but is V_g = 3 mV. However, it should be noted that this initial amount of V_g has no effect on the final results of the experiments because what is important is the difference of V_g before and after the collision
- The amount of gage factor also has an error of 1%, that can change the changes of this factor at the limit of 2/0691-2/1109. This amount shall change the results of the strain between ±2-3%. On one hand, there is also an error for the multi meter machine in reading the numbers related to the objects resistance that is equal to ±(0.8%+5 day) with the accuracy of 0.1 Ω. As a result, its effect rate is equal to ±8% on the result of the number for the strain
- Error of the anemometer is ±2% in the numbers read for the wind speed with the accuracy of 0.1 m sec^{-1}. In fact, its error has low effect on the results because the wind speed as one of the variables in the course of experiments and the number for it does not at all influence calculation of any results obtained from the experiments
- The multi-meter has an error equal to ±(0.5%+4 day) with the accuracy of 0.1 mV for reading the amount of V_g as well. As a result, the range of V_g changes may be increased or decreased by the same amount of 0.5%

The uncertainty made in reading the strain is:

$$\varepsilon = \frac{\Delta R / R}{G.F} = \frac{\Delta R}{G.F \times R}$$

$$\Delta\varepsilon = \frac{\partial\varepsilon}{\partial(\Delta R)}\Delta(\Delta R) - \frac{1}{R^2}\frac{\partial\varepsilon}{\partial R}\Delta R - \frac{1}{G.F^2}\frac{\partial\varepsilon}{\partial G.F}\Delta G.F$$

$$\Delta\varepsilon = 0.005 \times 0.1 \times 10^{-3} - \frac{1}{120.1^2} \times 0.0025 \times 0.3 - \frac{1}{2.09^2} \times 0.01 \times 0.0209 = -4.74 \times 10^{-5}$$

CONCLUSION

The following results can be understood for the conducted research that are expressed as the case may be: from the results obtained from experimental study of changed volume fraction of the dust, it is observed that as the dust imposed on the sample increases, the strain read by the strain gages increases as well, meaning increased load imposed on the sample.

From the results obtained from experimental study of changed speed, it is observed that as the speed increases, the strain increases as well and the cycle passed by the sample in the fatigue tester machine decreases until breaking and in other words, the lifetime of the sample decreases. Also, by imposing different speeds with a volume fraction of 30% of the particles content of the region winds, the lifetime of the sample may be increased to half. However, since in the study given by Dr. Khosravi, the most dust rate measured during the study period in May 2004 in low levels of the atmosphere (from 4 km high or less) is 2000 mg/m^3 (Khosravi, 2010) according to xrd analysis since, 70% of the dust consists of silica particles and the other 30% of calcite, the average density of the particles is 2633 kg/m^3. As a result, the volume of the particles in a cubic meter of the mixed air and dust is 8×10^{-4} with a volume fraction of 0.08%. On one hand, these measurements are made in the uppermost layers of the atmosphere but given the amounts provided, it is clearly that this amount may not exceed a volume fraction of 5%, e.g., 60 times more than it, under real conditions in the heights of about 40-50 m above the ground. As a result, the *in vitro* conditions here with the basis volume fraction are assumed to be 6 times harder than the real conditions.

Given the analysis of variance, the following general results are obtained:

- In a special speed, the more the volume fraction of the particles, the more the decreased lifetime
- Under real wind conditions that is a volume fraction of 5% when the wind speed is 18.5 m sec^{-1}, the decrease in the lifetime is 8.5% and in the speeds of 11, 5 and 7 m sec^{-1} this decrease will be the same for all, e.g., 6%
- If the volume fraction of the dust in the region air increases by 30%, the decreased lifetime reaches half. However, since the most dust content of the region air in the heights about 4-5 km over the ground in 2004 was 2000 mg/m^3 and this amount was considered exaggeratedly equal to 5% close to the ground surface such conditions with this volume fraction rate in the air is considered to be almost impossible

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