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STRENGTH ANALYSIS OF THE MAGNESIUM ALLOY CONTROL SYSTEM LEVER OF THE ILX-27 UNMANNED HELICOPTER

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Abstract

The article presents the potential use of magnesium alloys in the aerospace industry. In this project the static strength analysis of magnesium alloy AZ31 of the control – system lever of the ILX-27 unmanned helicopter was carried out. Control-system levers are located between the swash plate and an actuator. The aim of the tests was to confirm the strength properties of the magnesium alloy control-system lever for their implementation on the ILX-27 unmanned helicopter. Strain gauge sensor was used during the tests. Strain gauges installation on easily corrodes surface requires special method. The laboratory tests were proceeded by the lever static strength calculations in the computing environment ANSYS Inc. Additionally, a geometry measurement of the control-system lever at CMM equipped with a laser scanner head was made to compare with the lever CAD model to assess the quality and method of conformance. Unmanned helicopter ILX-27 is being developed through the introduction new materials and technologies. Tests of control system lever have shown if it is possible to use lighter materials than aluminum alloy to provide sufficient strength properties while reducing the mass of the object. Analysis of the available materials used in aerospace engineering allowed selecting the best of magnesium alloy.

Keywords: *magnesium alloys, FEM, strain gauges, geometry verification, strength test*

1. Introduction

The article discusses a new technology and materials applied in aerospace engineering, shows results of the numerical calculations in ANSYS environment and laboratory tests. As an example, a main rotor control-system lever made of magnesium alloy is shown.

The magnesium alloy has enjoyed a great deal of interest in the aviation industry for a long time. In the 1950s, it has been used, inter alia, in the experimental airplane F80C designed for the US Air Force, and the type S55 helicopter produced by Westland Aircraft LTD. The greatest advantage of magnesium, as a construction material, is its very low density which is only 1.74 [g/cm^3] (compared to the density of aluminium, that is 2.7 [g/cm^3], titanium of 4.4 [g/m^3] and steel 7.5-7.9 [g/cm^3]), making it one of the lightest metals. Since magnesium, as a pure material, does not have high strength and plastic properties, it is necessary to alloy it with other materials, such as aluminium, zinc, manganese, lithium, beryllium, silver, tin or zirconium. The most important addition to magnesium alloys is aluminium, which significantly increases tensile strength, as well as zinc and manganese. Silver increases the strength at high temperature, while the addition of silicon reduces fluidity and enhances brittleness. An impediment in the use of magnesium alloys is also its high cost of processing by plastic processing and difficult mechanical processing [1-4].

The project "Modern material technologies in aerospace industry" financed from the European Regional Development Fund proposes a number of solutions including a method for the die forging process of magnesium alloys [5-7].

In the Institute of Aviation, Warsaw, Poland, a series of tests of an AZ31 magnesium alloy control-system lever was conducted in order to consider a possibility of a potential use of these and other elements on the ILX-27 unmanned helicopter in the future [8-10].

2. The ILX-27 Unmanned Helicopter

The ILX-27 unmanned helicopter is a new construction designed at the Institute of Aviation in cooperation with the Air Force Institute of Technology (ITWL) and the Military Aviation Works No. 1 in Lodz (WZL-1).

The ILX-27 is a classic helicopter construction with a single, three-blade main rotor, a ducted fan tail and a piston engine. Unique features of this construction include a fully autonomous flight mode with take-off and landing, a long-distance communication protocol, a reconfigurable fuselage structure, 5G crash-landing gear, hi-tech composite blade manufacture method and dimensions that allow transport in a standard ship container [11, 12].

2.1. The control – system lever

Control-system levers are located between the swash plate and an actuator (Fig. 1). Therefore, the levers are one of the most loaded elements of the unmanned helicopter control system.

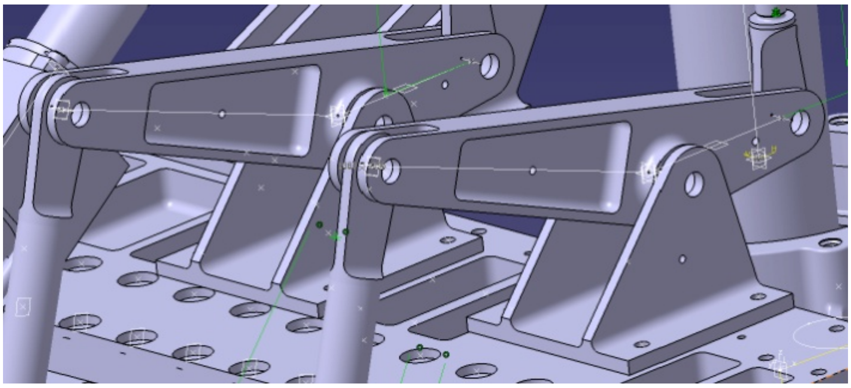


Fig. 1. Control – system levers 3D model in Catia

Originally, control-system levers were designed and made of PA7 aluminium alloy, which is widely used in the production of machines and vehicles parts, especially in aviation because it is capable of carrying heavy loads with a relatively small weight.

The control-system lever was made of magnesium alloy AZ31 in an innovative forging die process. A new method of die forging was developed at the Technical University of Lublin during the project "Modern Material Technologies in Aerospace Industry" [13-15].

In aerospace engineering, lightweight construction parts are very important. Through the use of magnesium, whose density is 1.74 [Mg/m^3] the reduction of product mass by 30% is achieved as compared to the previously used aluminium alloys.

The weight of a lever made of PA7 aluminium alloy is approximately 321 g, while the weight of the AZ31 magnesium alloy lever is around 35% lower and is 207 g.

3. Az31 alloy lever geometry verification

The geometry of the levers was verified to confirm the accuracy of the die forging process. For this purpose, reverse engineering was used. Measurement was made using the CMM equipped – LK V HA with a laser scanner head LC15Dx with an accuracy up to 1 µm. The measurement results are saved in the form of point clouds as a matrix of the coordinates of individual points (x, y, z). Then, in the process of triangulation, surfaces of three-dimensional objects are obtained. In order to get answers about the accuracy of the object (in our case the control – system lever) the CAD model was compared with the model obtained in the CMM measurements (Fig. 2).

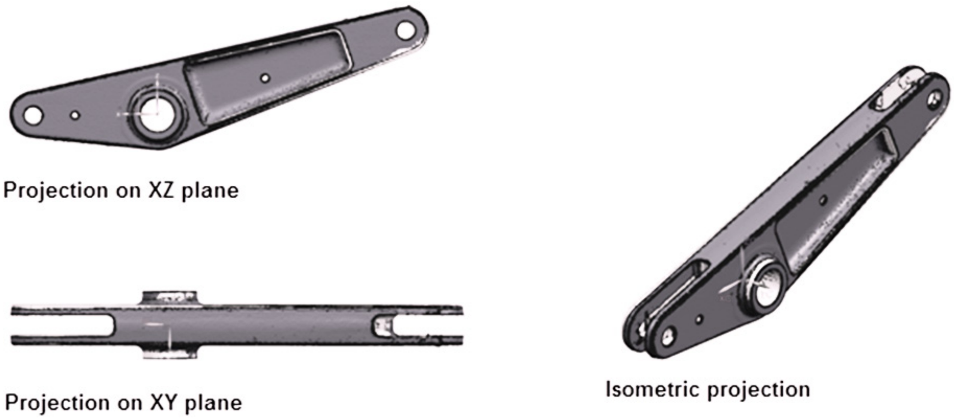


Fig. 2. Projection on plane superimposed: CAD model (light grey) and measuring object (dark grey)

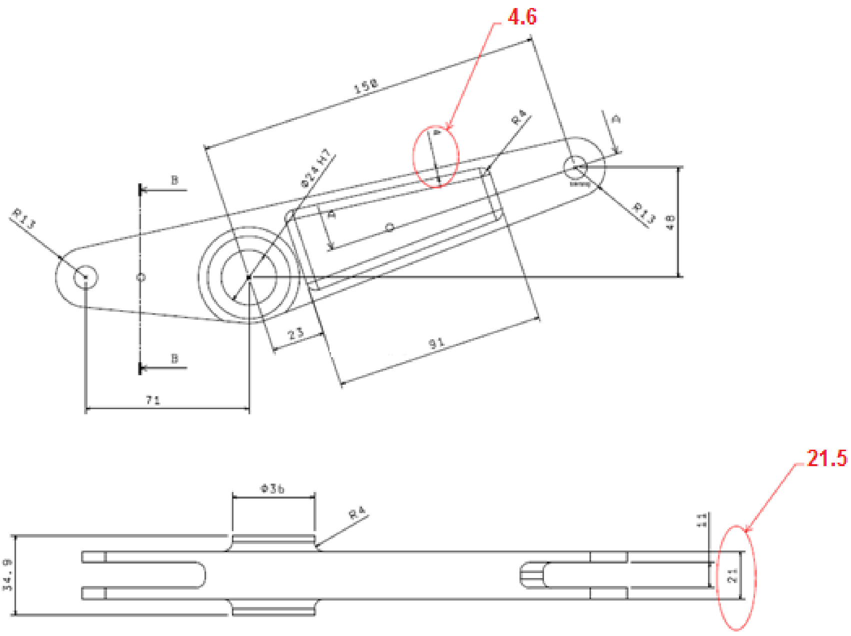


Fig. 3. The most visible changes in the magnesium alloy control – system lever geometry

4. AZ31 alloy lever static strength calculation

First, the behaviour of the lever under load related to the flight of an ILX-27 unmanned helicopter was checked. For this purpose, static strength calculations were performed using the structural computation environment ANSYS Inc. [16]. For them operational loads occurring in the control system during the ILX-27 unmanned helicopter flight were assumed. Values of loads were received after analyses of the helicopter flight data.

In this case, the maximum loads acting onto the control - system levers were assumed, and for the calculations, loads of 2,000 N were assumed.

Calculation was carried out for the AZ31 magnesium alloy control – system lever of the material data listed in Tab. 1, [17-20].

Tab. 1. AZ31 alloy properties

ρ [kg/m^3]	E [Pa]	ν [–]	$R_{e0.2}$ [MPa]	R_m [MPa]
1770	0.459e11	0.35	160	260

4.1. FEM analysis results

According to the FEM (Finite Elements Method) simulation, the control-system lever operates in elastic deformation and the point stress concentrations caused by the notch effect do not exceeding yield strength or ultimate tensile strength of the material for the assumed magnesium alloy AZ-31.

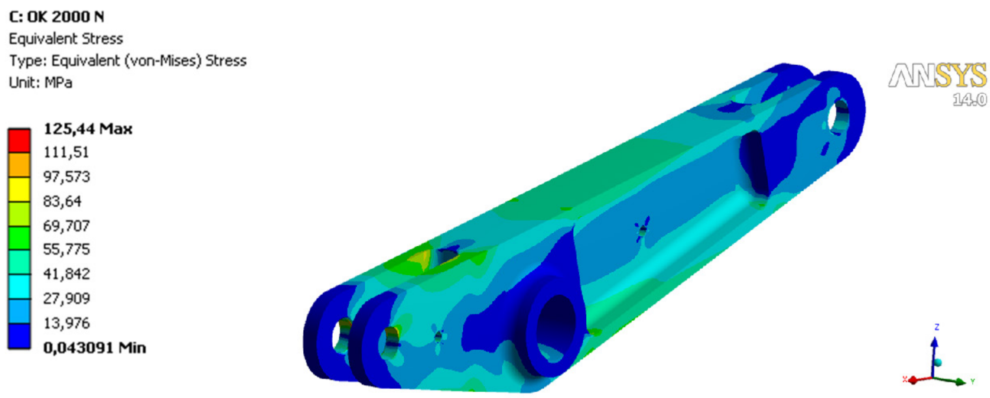


Fig. 4. Stress distribution of the control – system lever

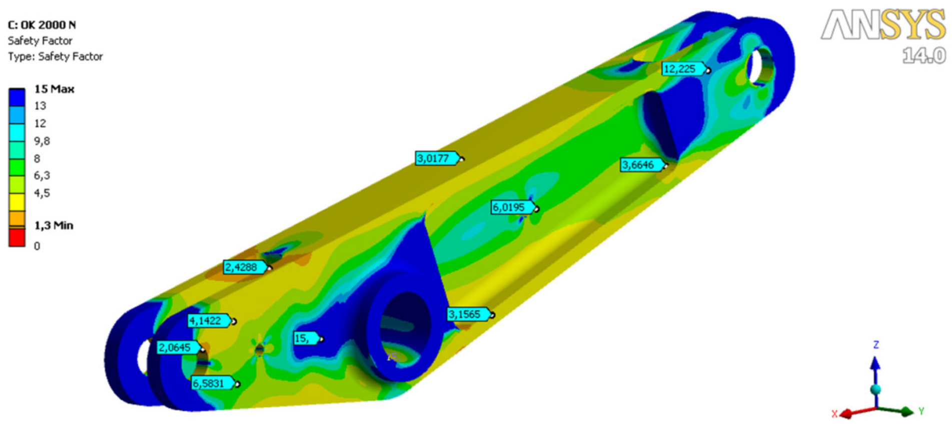


Fig. 5. Distribution of the safety factor on the control – system lever

5. AZ31 alloy lever static strength tests

Prior tests on the test stand control-system lever were prepared in accordance with the technical documentation and mounting instructions for the ILX–27 unmanned helicopter. Additionally electrical resistance strain gauges were installed to verify the strength and deformation at selected points of the lever.

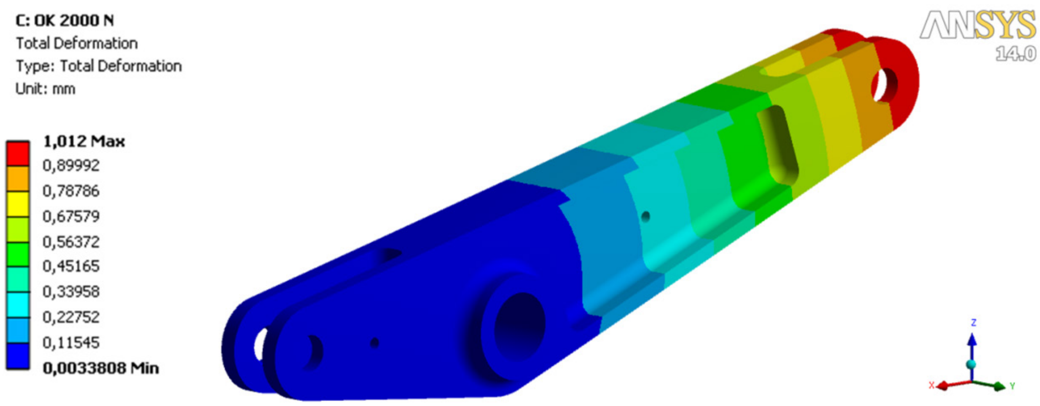


Fig. 6. Total displacement of the control – system lever, isometric view

5.1. Test stand

The test stand consisted of the parts, which enforce the load, parts fixing the test object and parts for data acquisition. The control-system lever was mounted at two points, by shorter arm and through the ball - bearing hole.

Loads during the test were carried by a hydraulic actuator. The level of loads and lever deformation were controlled by the measurement system SPIDER 8 with PC application.

5.2. Strain gauge installation

In order to verify the level of lever deformation during the static strength tests, strain gauges were installed on the lever. Strain gauges were installed in points specified as sensitive during the FEM analysis (Fig. 7). The data acquisition system allowed the verification of the state of deformation during the tests. Strain gauge installation with cyanoacrylate adhesive is a process, that requires precision and accuracy and in the case, when the surface corrodes easily after preparation for installation of sensors, it is a challenging method. The corrosive surface area causes the strain gauges to detach from the surface instead of bonding with the lever. A properly glued strain gauge is key to correct measurement.

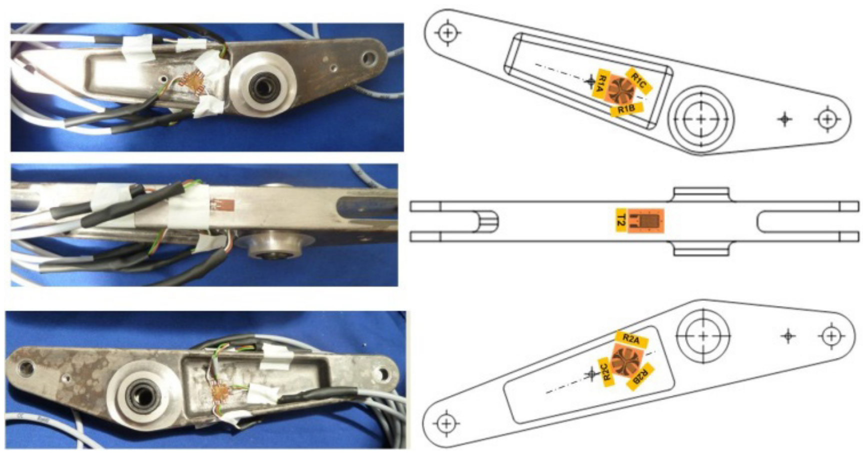


Fig. 7. Strain gauge points installation

5.3. Tests methodology

The test was conducted in three stages. The first stage consisted of verifying the measuring equipment and data acquisition system as well as test stand clearance removal. In the second stage, a static strength test of the control-system lever was made. The test was carried out to verify the FEM calculations. The third stage was a DT test (Destructive Testing) of the control-system lever. The load values are shown in Tab. 2.

Tab. 2. Test stages and loads

Stage	Loads [N]
1	1000
2	2000
3	Over 2000 until destruction

5.4. Tests results

Figures 8 and 9 show the characteristics of deformation of the control-system lever to the load 2000 N. Plastic deformation of the control-system lever did not occur during the test and the indications of the strain gauges returned to the initial values noted prior to the test.

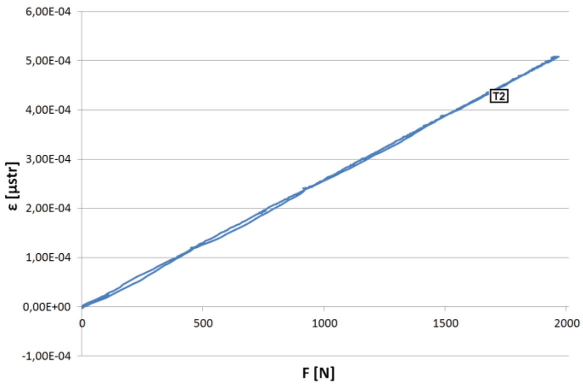
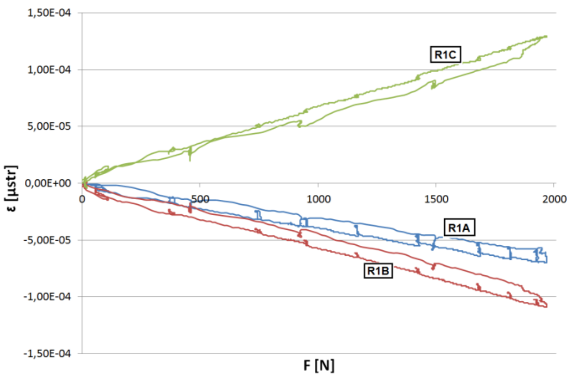


Fig. 8. Deformation values for loads 2000 N, reading of the unidirectional strain gauge T2

A)



B)

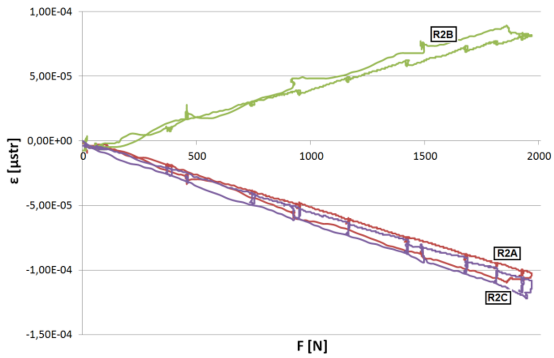


Fig. 9. Deformation values for loads 2000 N, reading of the strain rosette A – R1, B – R2

During the DT test, we can distinguish two phases of lever destruction. Plastic deformation of the lever occurred in the first phase, while in the second phase the lever fractured. It was still capable of carrying even higher loads, but deformation started to increase rapidly, so the decision was taken to stop the test at that point. In Fig. 10 there is force presented in function of time. The first value corresponds to the beginning of the plastic deformation, as mentioned previously. The second value points to the crack of the lever and a small drop of the force can be seen due to the displacement of the lever. After that, the lever started not only to deform, but also to twist, as shown below.

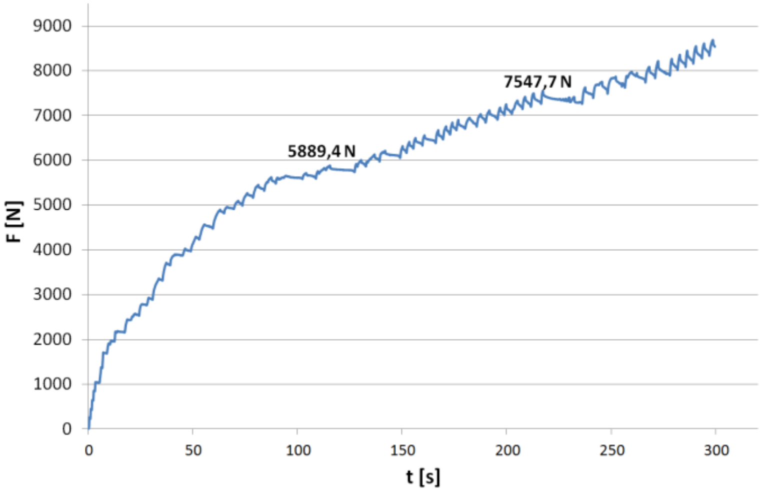


Fig. 10. Force value during time of the destruction test

6. Conclusion

The main goal of these tests was to prove that the lever could be safely tested in real conditions, which occur on the unmanned helicopter. Additionally, the FEM analysis model was checked. All tests proved the possibility of mounting the lever on the unmanned helicopter. The obtained safety factor is almost 2.5, which is sufficient for critical parts according to aviation requirements. Even after a plastic deformation, the lever is capable of resisting larger forces without a complete destruction, so an emergency landing can be performed, because continuity in that line of control system is preserved.

Work on this project will be carried on. Due to high plasticity, another step will include a long endurance fatigue test. This is necessary in order to ensure that nothing will occur when a changeable force acts on the lever for a long time. After performing such a test and confirming, that everything is works well, final tests can be made on the flying prototype. This will be the end of the test cycle and after 100 hours of flight; it will be able to be used as certified aviation part.

Acknowledgements

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