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ISSN 0543-5846
METABK 61(3-4) 801-803 (2022)
UDC – UDK 669.15:621.778:537.312.62:66.04:539.43=111

INFLUENCE OF HEAT TREATMENT ON FATIGUE PROPERTIES OF 6101 SERIES ALUMINIUM ALLOY WIRES

Received – Primljeno: 2021-10-29
Accepted – Prihvaćeno: 2022-03-10
Preliminary Note – Prethodno priopćenje

AAAC conductor fatigue resistance in overhead power lines is critical for electrical safety and stability of power transmission system. The article discusses the influence of the artificial aging of 6101 series aluminium alloy wires on their operational properties. Moreover, the influence of the proposed heat treatment on the fatigue strength and the nature of breakthroughs of the tested wires was compared.

Keywords: 6101series aluminium alloy, wire, conductor, fatigue resistance, heat treatment,

INTRODUCTION

The most important element of the electricity transmission infrastructure are overhead power lines and each of the them is constantly subjected to the influence of weather conditions, which cause the occurrence of varying throughout time mechanical stresses [1]. Material fatigue being the result of varying stress caused by wind vibrations is on of the most dangerous phenomena as in extreme conditions it may be the reason for damaging or even destroying the power line [2,3]. The occurring problem is known and been studied for years among all types of overhear power lines currently in use [4]. The discussed issued is particularly significant in the case of AAAC power lines as they do not have a steel core which additionally transfers mechanical stresses. However, such power lines have a number of advantages including but not limited to increased current carrying capacity, lower weight and lack of corrosion at the place of contact between core and wires [5-11]. The 6101 alloys which are usually chosen for these types of power lines allow for the shaping of mechanical and electrical properties on a wide range using low temperature heat treatment [12]. What is more the use of artificial aging makes it possible to obtain a material with increased fatigue resistance.

EXPERIMENTAL PROCEDURE

The research on the heat treatment and its effect on the operational properties and fatigue strength were conducted on commercial Φ3,12 mm EN AW-6101A wires dedicated for electrical purposes with a chemical composition specified in Table 1.

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Table 1 **Chemical composition of EN AW-6101A wires / wt. %**

Al	Mg	Si	Fe	Cu	other
98,3	0,40-0,90	0,30-0,70	0,40	0,05	0,10

Heat treatment

6101 aluminium alloy belongs to the series of precipitation hardening alloys due to the presence of silicon and that is why it is susceptible to heat treatment. The conducted research present results of artificial aging carried out in a Memmert UFE500 laboratory convection oven in temperatures 140 °C, 160 °C and 180 °C with the times ranging from 15 minutes to 9 hours. Therefore, three different sets of samples with various properties were obtained and used for further research.

Tensile strength

Using ZwickRoell Z020 testing machine the mechanical properties of the heat treated materials were determined in the uniaxial tensile test conducted in the ambient temperature with gauge length of samples of 250 mm and the results were used to determine the aging curves.

Electrical properties

The intended use of the tested wire requires a certain level of electrical properties, thus the electrical aging curves were determined using Kelvin-Thomson bridge for resistance measurements. The results were obtained using Resistomat 2304 device with measurement accuracy of $\leq$ 0,01 % and the test was conducted in controlled conditions in ambient temperature with a gauge length of 1000 mm.

Fatigue resistance

The fatigue resistance was determined using especially designed test stand presented at Figure 1 operating in rotational bending mode. The stress was applied by an appropriate deflection arrow and the stress variability was caused by the rotation speed of 3 000 rpm. The test was carried out until the breakage of samples.

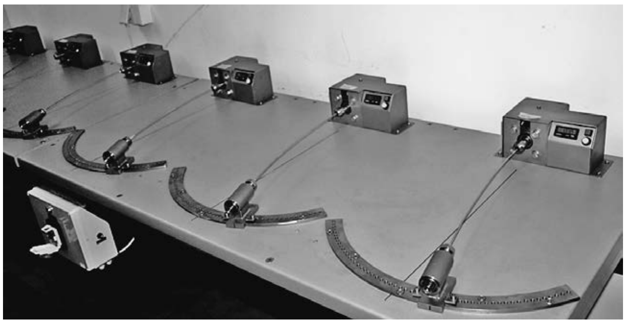

Figure 1 Fatigue resistance test stand (rotational bending)

Microstructural analysis

The obtained fatigue fractures were analysed using Hitachi S-3500N scanning electron microscope (SEM).

RESULTS AND ANALYSIS

Mechanical properties after heat treatment

The obtained mechanical properties of the studied materials in the function of artificial aging time with temperature distinction were presented at Figure 2.

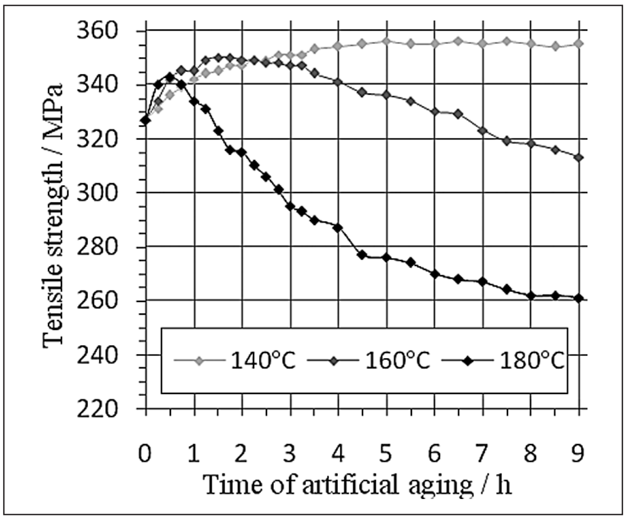

Figure 2 Tensile strength of Φ3,12 mm wire in the function of aging time

In all of the studied cases, an increase in strength properties to a certain maximum value is visible. However, at 140 °C the material reaches the maximum at 356 MPa after 5 hours and remains at the constant level regardless of the further applied time of heat treatment. For 160 °C the maximum of 350 MPa is reached after 1,5 hour, with further stabilization of properties up until 3,25 hour of aging. At 180 °C the material reaches a maximum value of 346 MPa the fastest, however, it is lower than in other cases and the increase of aging time results in a rapid decrease of the material strength.

Electrical properties after heat treatment

The electrical properties of the 6101 aluminium alloy are also directly correlated with the parameters of the applied artificial aging parameters. The data on electrical resistivity in the function of time are collectively presented at Figure 3 with temperature distinction.

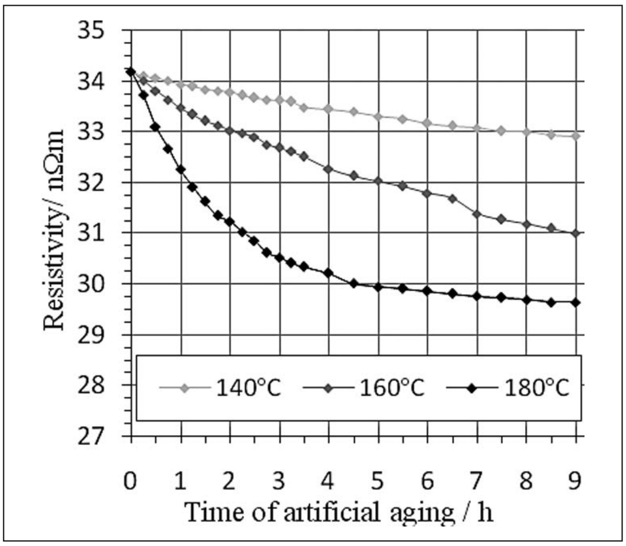

Figure 3 Electrical resistivity of Φ3,12 mm wire in the function of aging time

Among all of the studied cases the decrease of electrical resistivity of the tested samples was noted as the time and temperature of the artificial aging were increased.

Fatigue resistance

The application of tested wires requires a certain compromise between mechanical properties and decrease of electrical resistivity obtained as a results of heat treatment. Bearing that in mind for the comparative fatigue tests materials subjected to 160 °C were selected with a maximum strength value obtained after 2 hours and the overaged material after 9 hours with a raw material as reference. S-N Wohler curves obtained by rotational bending were presented at Figure 4. In all of the analysed cases with high stress values the number of

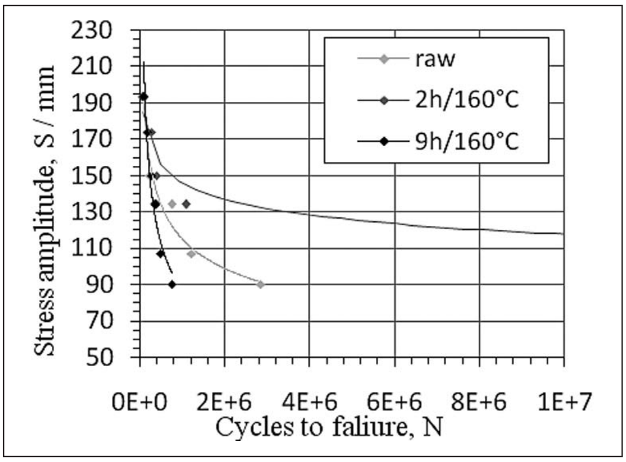

Figure 4 Wohler S-N curve for selected variants of aging

cycles to failure was similar, however, the characteristics diverge as the stress amplitude decreases. The reason for that may be that with high stresses the most significant in the fatigue failure process are e.g. material defects and as the stress decreases other mechanism such as dislocation and boundary migrations begin to matter. The obtained S-N curves clearly indicate that the material after 2 hours at 160 °C had the highest fatigue strength whereas the lowest was observed with the overaged material (9 hours at 160 °C).

Fatigue fractures

The fracture analysis of the wires subjected to rotational with the stress amplitude of 100 MPa was presented at Figure 5 and suggests that the applied heat treatment has a significant influence on the surface of fatigue fracture.

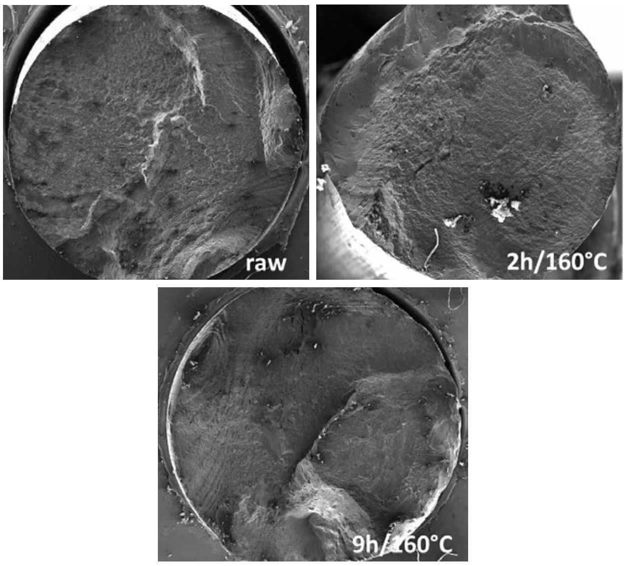

Figure 5 Influence of the heat treatment on the surface of AlMgSi wires after rotational bending fatigue resistance test

Wires with no heat treatment seem to have similar fracture to overaged samples after 9 hours of aging. In both cases the fracture surface was developed with clearly visible primary cracks, both surfaces are covered with brittle stripes, and what is more both materials had many residual fractures of similar size. However, in the case of the sample after 9 hours of aging the wire had bigger and more numerous secondary cracks which indicates unfavourable effect of overaging on the fatigue strength. The wire with a highest strength value i.e. after 2 hours of heat treatment shows significantly greater residual fractures and less developer surface with lower amount of internal defects and structural damage. Morphology comparison of the fractures after various heat treatment shows an increase in the residual fracture as the aging time increases up to the strength maximum of the material after which the phenomenon disappears.

CONCLUSIONS

The 6101 aluminium alloys allows for a wide range of properties modification by heat treatment as applied artificial aging improves mechanical and electrical properties of the materials. In the wires used for AAAC overhead power lines it is crucial to obtain high values of strength and electrical properties at the same time. What is more it is possible to select the heat treatment parameters in such a way that it will additionally increase the fatigue strength of the wires used for power lines. Increasing the wires and therefore the power lines resistance to high frequency vibrations of low amplitude, which is the most common cause of fatigue damage of overhead power lines is especially important.

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Note: The translator responsible for English language: Grzegorz Kiesiewicz, AGH University of Science and Technology, Kraków, Poland