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The effect of anodising on the fatigue performance of self-tapping aluminium screws

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ABSTRACT

Self-tapping aluminium screws are an innovative joining technology for the assembly of lightweight components in industrial scale. It has been established in the past that porous anodic oxide coatings in many cases reduce the fatigue strength of specimens without notches. In the present work, the fatigue behaviour of notched specimens, i.e. self-tapping screws made from aluminium alloys EN AW-6056, 6082 (both in a conventional state and in a fine-grained state produced by equal channel angular pressing – ECAP) and 7068 with and without oxide coatings is examined. The coatings are produced by hard anodising and are necessary for the thread-forming process during assembly. While the coatings do not affect the static tensile strength, they reduce the fatigue strength for the specimens of the 6056 and the 6082 alloy. For the 7068 alloy a slight increase in fatigue strength is discovered on a low load horizon. The scatter of endured fatigue cycles until fracture of specimens is generally reduced by the anodic oxide coatings.

1. Introduction

The successful application of lightweight materials in industry requires appropriate assembling techniques, i.e. joining concepts. For the light metals aluminium and magnesium and also for plastics, self-tapping screws represent an innovative joining technology. The use of high-strength aluminium alloys as screw material is favored for the joining of lightweight materials compared to the application of steel screws due to reduced loss of clamping force and the avoidance of galvanic corrosion. To ensure the correct forming of the thread in the joining process, a surface modification of the self-tapping aluminium screw is required. The formation of an aluminium oxide layer on the screw surface based on anodising or hard anodising leads to a significant reduction of the torque, which is required for the thread-forming process, and to an enhancement of the corrosion resistance [30,31]. Thus, it is possible to use self-tapping aluminium screws to join even high-strength aluminium alloys, e.g. those of the 2XXX or 6XXX series.

In the past, it has been proven in many cases that the fatigue performance of aluminium is reduced by anodising in the course of which a porous alumina layer is formed on the surface. This is mainly caused by the following effects: (1) Under cyclic load, cracks are preferably initiated at pores and flaws in the coating [2,3,6,16,18–20,22,25,30]. The low ductility of the aluminium oxide enhances this effect [6,7,30]. Cracks that are initiated in the oxide coating propagate into the substrate [13,29]. (2) The technological process of anodising includes etching as a pre-treatment. Depending on the alloy, dissolution of precipitates in the alloy or dissolution of the aluminium matrix around precipitates can occur. At these sites, cracks can preferably initiate [4,5,27,30]. For some aluminium alloys, the dissolution of microstructural constituents can also occur during anodic oxidation, which generates flaws acting as a crack initiation site [21,24,28].

Screws contain many notches based on their geometry. Considering this geometric effect, it has to be examined to which extent the formation of a porous aluminium oxide layer affects the fatigue performance, which, up to now, has only been investigated for plain aluminium parts without the presence of notches.

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2. Experimental procedure

Different types of screws have been investigated with respect to their fatigue performance. Self-tapping screws (alloys EN AW-6056, EN AW-7068) of the dimension M6 × 35 were examined as well as screws of the dimension M10 × 50 (EN AW-6056, EN AW-6082). The chemical compositions of the alloys are given in Table 1. In order to get generalized results regarding the fatigue performance of series production screws, the samples were taken from a production batch, which may generally include different material batches. Therefore, Table 1 shows the ranges of the material composition.

2.1. Production of screws

The M6 screws (EN AW-6056, EN AW-7068) were taken from a series production process using state-of-the-art technology (EJOT, Germany) where the heat treatment was the final step in the process chain. The M10 screws made from EN AW-6056 alloy were also taken from a series production process in which thread rolling was the last step of the production chain. For the EN AW-7068 alloy, the overaged T73 heat treatment state was used due to the lower susceptibility to stress corrosion cracking of the alloy in this condition. EN AW-6056 screws were tested in the T6 heat treatment state. The M10 screws made of EN AW-6082 alloy were tested in two different states of one material batch, which required an adaption of the process chain in which the thread rolling process was the last step. The screw blanks of the EN AW-6082 alloy were produced by machining compared to other screws which were produced by cold forming. One state of the 6082 screws was the heat treatment state T651 (microstructure was only modified by a thread rolling process). The other state is characterised by an ultra-fine grained microstructure. This state was produced by equal channel angular pressing (ECAP) in one pass. Subsequently, a heat-treatment process was performed to optimise the material with respect to hardness and ductility. The abbreviation used to address this material condition is E1opt [14].

All of these five variants of screws were subjected to an anodising process. For this purpose, the screws were pre-treated by etching in 3% sodium hydroxide at 50 °C for 5 min and pickling in 30% nitric acid at room temperature for 30 s. Each of the steps was followed by a rinsing process under deionised water. The anodising process was carried out in a laboratory plant. The process was performed in an electrolyte of 1 mol per litre sulphuric acid at a temperature of 5 °C or 20 °C for 1 h. The process was galvanostatically controlled with a current density of 2 A/dm^2, which resulted in a porous oxide coating with a thickness of approx. 30 μm. After the anodising treatment, the screws were rinsed under water and dried subsequently.

The effect of hard anodising on the fatigue performance of the aluminium screws was examined for the five different types of screws, which cover different materials, heat treatment states and geometries. Together with the surface modification, eleven experimental series with different configurations, which are then compared with respect to their fatigue performance, have been evaluated. The abbreviations used to address the different specimens are given in Table 2.

2.2. Static strength tests

In order to define the parameters for the investigation of the fatigue behaviour of aluminium screws, static strength parameters are required. Therefore, strength values given in material data sheets are compared to values obtained from tensile tests. Furthermore, information should be generated whether the formation of the porous alumina layer by anodising affects the static strength. It is considered that only the screws made from EN AW-6082 (M10) are of the same batch of material. The surface modification was realised batch-wise, i.e. all specimens of every variant of surface modified screws were produced in one batch each. Static strength tests were performed with a universal test machine Zwick SM Z050/TH3S (Zwick, Germany). The test setup is shown in Fig. 1. Seven specimens per variant were tested for the self-tapping screws (M6). For the reference screws (M10_6082_xxx), three specimens per variant were tested. The specimens for the static strength test were manufactured by turning according to DIN EN ISO 898-1 [8], Fig. 2.

2.3. Fatigue strength tests

The effect of hard anodising on the high-cycle fatigue strength of the aluminium screws was examined at two different load horizons. The constant mean tension σ_m was amounted to 70% of the 0.2% proof stress of the unmodified aluminium. The values for the 0.2% proof stress were obtained from the datasheet [10] for the self-tapping screws (M6_xxx), see Table 4. For the M10_6082_xxx series, the 0.2% proof stress was obtained from tensile strength tests of samples of the material batch in the states T651 and E1opt. The deviation of the values obtained from the tensile strength tests of the material batch from the values obtained from the tensile strength test of the reworked screws was less than 2%. For the screws M10_6056_xxx, the test parameters were identical to that for the M10_6082_E1opt series, which allows for the comparison of these series.

The tension amplitude σ_a of the first load horizon was 45 MPa except for the M6_7068_xxx series (33 MPa). The tension amplitude of the second load horizon was 29 MPa for the M6_6056_xxx series, 21 MPa for the M6_7068_xxx series and 27 MPa for all the other series. Thus, it was approx. 36% (M6) or 40% (M10) smaller compared to the first load horizon. The variation of the tension amplitudes arises from a deviation of the load cycles the series endured. Table 3 summarises the constant mean tension and the tension amplitudes of the two load horizons for the tested specimens.

The fatigue strength tests were performed with a magnetic resonant testing machine Testronic 100 kN (Russenberger, Switzerland). The gripping device was manufactured according to DIN 969 [9]. The mean load and the load amplitudes were exerted by the testing machine according to DIN 969. The mean forces and the force amplitude were defined on the basis of the tension cross section of the specimens A_s and the core cross section A_{d3}, respectively. A steel fixture with an M6 thread was used for the self-tapping M6 screws. Steel nuts of strength category 8 (DIN 934) were used to fix the M10 screws. The testing frequency was 61 Hz and 71 Hz for the M6 and M10 screws, respectively. Every

Table 1
Composition of the alloys used in the experiments (in wt.%) [1,10].

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Al
EN AW-6056	0.7–1.3	0.5	0.50–1.1	0.40–1.0	0.6–1.2	0.25	0.10–0.7	Max. 0.20		Bal.
EN AW-7068	0.12	0.15	1.6–2.4	0.10	2.2–3.0	0.05	7.3–8.3	0.1	0.05–0.15	Bal.
EN AW-6082	0.7–1.3	0.50	0.10	0.40–1.0	0.6–1.2	0.25	0.20	0.10	–	Bal.