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Applicability of high strength thread forming Aluminum bolts in magnesium power train components

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Abstract

Aluminum thread forming bolts in combination with magnesium clamping parts in power train components offer a high potential to save costs and weight. This paper discusses the applicability of high strength thread forming bolts in magnesium nut materials focused on mechanical properties of the aluminum bolt and the Mg-nut material, creep and relaxation as well as corrosion behaviour of the bolted joint.

Introduction

The current state of technology for fastening magnesium power train components is the use of metric steel or aluminum bolts. Due to physical and chemical properties of the used materials, difficulties like high clamping load loss at elevated temperatures and strong corrosive attack which requires costly corrosion protection systems must be taken into account. The objective of this paper is the development and to evaluate a high strength thread forming aluminum bolt for magnesium components regarding mechanical properties, relaxation and corrosion behavior. Benefits of this bolt connection system are weight reduction in comparison to steel bolts, lower loss of clamping load, less contact corrosion and cost reduction by using thread forming technology (elimination of drilling and thread cutting operations).

Power train components such as gear boxes are currently manufactured predominantly from aluminum alloys. The pressure to reduce CO_2 emissions forces OEMs and suppliers to reduce the weight of vehicles. One option for doing so is to replace aluminum alloys with magnesium alloys. However magnesium requires the fastening technology to be adapted – especially with regard to corrosion and relaxation.

Requirements of bolt connections in Heavy-Duty Magnesium Components

Under the influences of temperature, force and torque loads, bolted magnesium components tend to creep and relax. In addition, magnesium – when bolted together with steel bolts – suffers high corrosive attack due to the high negative standard electrode potential of magnesium. When designing the bolted joints with magnesium alloys, the following points need to be considered:

- Corrosion in the presence of electrolytes
- Creep and relaxation, especially at service temperature above 120°C
- Rigidity characteristics dependent on temperature and ageing
- No marked endurance strength

The following requirements are derived for bolted joints in power train components:

- Minimum clamping load over entire product life time
- Temperature resistance to minimum 120°C at the bolted point
- Sufficient failure-safety against the collective service load
- 720 hours corrosion resistance in the salt spray test, as per ISO 9227:2006

Thread forming high-strength aluminum bolts used for magnesium alloys provide considerable potential for reducing cost and weight and cause a strain hardening effect on the nut thread. Further additional requirements must be defined, when using thread forming aluminum bolts in magnesium power train components.

- Use of pre-cast core holes in magnesium component for optimum cost reduction
- Definition of sufficient core hole tolerance for reliable casting processes in bulk production
- Assembly reliability (low forming torques with failsafe against pull-out and breaking)
- Generation of sufficient assembly clamping loads with sufficient distance between forming and tightening torque when applied over the entire core hole tolerance range.
- Serviceability: Possibility to reuse formed magnesium nut threads in service case either with thread forming or metric bolts.
- Resistance against galvanic corrosion and stress crack corrosion.

Thread forming technology

Current solutions that are frequently used for magnesium bolt connections in exposed fitting situations are steel bolts with aluminum cup washers (or other head encapsulations) or metric aluminum bolts in EN AW 6056 alloy. Alternatively to metric bolts the use of thread forming bolts can be considered. In the mechanical production process for the housing, the cost can be reduced because drilling and thread-cutting work steps can be eliminated. State of the art is the use of steel thread forming bolts with aluminum housings. In this work the application of a thread forming aluminum bolt with TAPTITE2000® geometry in different Mg die cast alloys is investigated.

Material selection

Mg-alloy

The application of the commonly used magnesium die cast alloy AZ91 in automotive power train components is limited by its poor creep resistance at elevated temperatures. Components such as gear boxes can be exposed to temperatures of 120 °C and higher during operation. The reason for the limited creep performance of the Mg-Al based alloy AZ91 (Mg-9Al-1Zn) is the formation of $Mg_{17}Al_{12}$ phase during solidification and at elevated temperatures out of the supersaturated solid solution [1,2].

In the past decades, a lot of effort has been put into developing creep resistant Mg-alloys by adding specific alloying elements. The mechanism for the superior creep behavior of these alloys is partly the formation of thermally stable precipitations and furthermore, the prevention of precipitation of $Mg_{17}Al_{12}$ phase by adding elements with higher chemical affinity to Al than Mg.
[3] describes these mechanisms in both the AE and AJ alloy systems. In [4] the MRI153 as Mg alloy for power train applications is presented.

The die cast alloys AZ91, AE44 and MRI153 were selected for closer experimental investigation concerning creep behavior, relaxation, thread forming process and corrosion. AZ91 represents the currently most used standard Mg alloy with the highest production mass. AE44 and MRI153 are considered as potential Mg alloys for automotive power train components with improved elevated temperature properties.

Bolt material selection

When using thread forming bolts it is important to consider work hardening effects in the nut material occurring during the thread forming process. Most publications and standards do not account for this fact as they exclusively refer to machined metric nut threads in combination with metric ISO threads [5, 6].

Aluminum bolts that are currently being used predominantly with machined threads are typically made of the alloys EN AW 6056 (AlSi1MgCuMn) and EN AW 6013 (AlMg1Si0,8CuMn) with tensile strengths between 380 and 400 MPa [5, 7]. Thread forming aluminum bolts require higher strength due to the nut materials' resistance when forming the thread. This is the case especially with die casted core holes and high thread coverage (lower core hole tolerance). To achieve sufficient clamping load levels with thread forming aluminum bolts, the high strength alloy EN AW 7075 (AlZn5,5MgCu) was chosen and investigated [5,6]. In the heat treatment condition T6 with final production step thread rolling, a tensile strength of up to 550 MPa is achievable. This hard condition is advantageous for thread forming.

Figure 1 a and b shows the comparison of the tightening process until bolt failure of thread forming M8x1.25 aluminum bolts EN AW 6056 T6 and EN AW 7075 T6 into pre-cast core-holes of AZ91 at lower core hole tolerance (LCT). The same friction control coating (OKS) was used with both bolt types.

The EN AW 7075 T6 bolt reaches a higher failure torque due to its higher material strength. The forming torque of the EN AW 6056 T6 bolt is significantly higher. Metallographic investigations show that this can be explained as a consequence of exceeding the yield strength locally. Plastic deformation of the thread flanks occurs and leads to a higher forming resistance. This is not the case with the EN AW 7075 T6 alloy. The combination of lower forming torque and higher failure torque yields a larger available torque range for building up clamping load. 8 kN of average clamping load were measured with 6056 bolts, 12 kN with 7075 bolts. Furthermore, too low an angle window between head contact and failure, as it is the case with the 6056 alloy, leads to a non capable assembling process. Therefore the EN AW 7075 alloy was selected for further investigations.

Tightening process

When using aluminum bolts, only an over-elastic tightening procedure enables clamping load levels similar to steel bolt connections due to the reduced material strength. This is pursued by a torque and angle controlled tightening and results in little scattering in clamping load. Tightening exceeding the yield strength of the bolt requires high strength in combination with sufficient ductility to avoid bolt failures during tightening.
The two investigated thread forming aluminum bolts TAPTITE2000® M8 EN AW 7075 differ in the heat

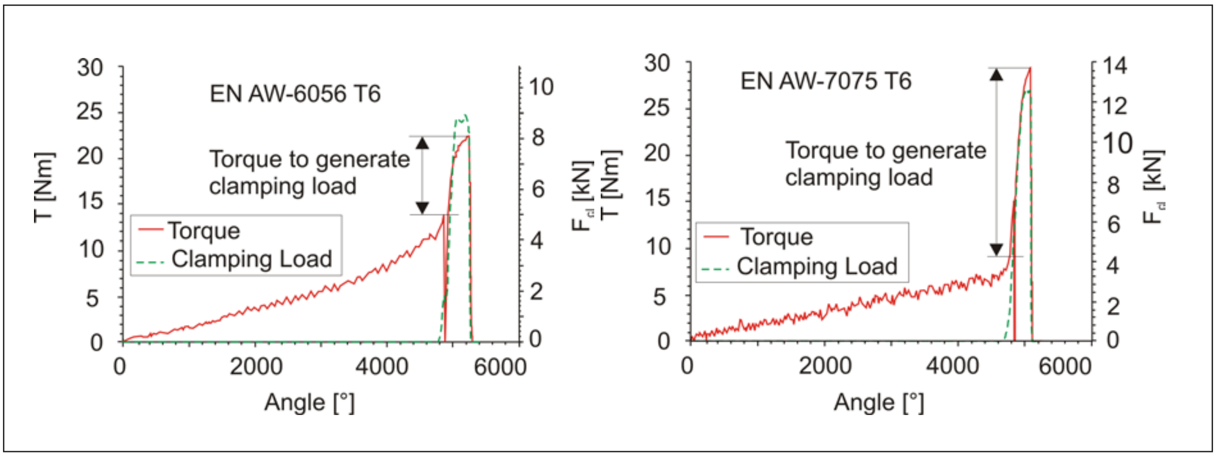

Figure 1. Tightening process in pre-cast core hole of AZ91 with TAPTITE2000® M8x EN AW 6056 T6 (a); with TAPTITE2000® M8 EN AW 7075 T6 (b) [8]

treatment condition as well as in the final production step. The aluminum bolt in heat treatment condition T6 has maximum material strength in combination with moderate ductility due to coherent and partly coherent precipitations. When overageing from T6 to T79, a certain decrease of material strength has to be accepted because of changes in the matrix–precipitation interfaces [11]. However, ductility expressed by breaking elongation increases significantly as shown in figure 2. The bolt in condition T6 was thread rolled as final production step (FTR…Final thread rolling) whereas the bolt T79 was finally heat treated (FHT…Final heat treatment). In the following, the two bolts are named as EN AW 7075 and EN AW 6056 with the according heat treatment condition and the final production step.

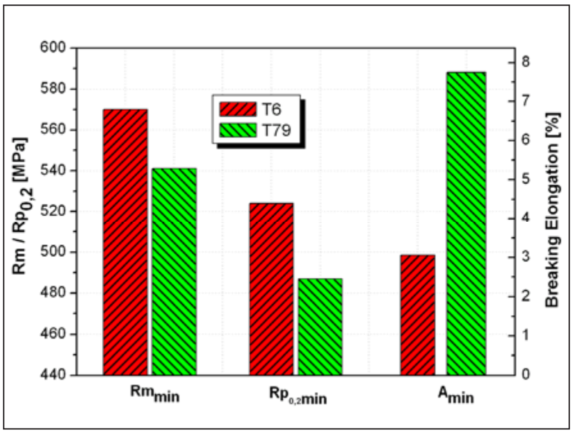

Figure 2. Minimum tensile strength Rm, yield strength $Rp_{0,2}$ and breaking elongation of M8 EN AW 7075 in T6 and T79 heat treatment condition and different final production step

Static bolting tests were performed to investigate and evaluate the tightening properties of both bolts. Bolts in two heat treatment conditions T6 (highest strength state) and T79 (overaged state) were bolted into pre-cast AZ91 core holes with minimal (UCT…upper core hole tolerance limit) and maximum (LCT…lower core hole tolerance limit) thread coverage. Core holes must be cast in order to optimize process costs. Due to wear of die and core pins over lifetime, variations in the core hole size occur. Together with die casting experts, achievable tolerances have been specified. Within this study the two limits of this defined tolerance range (LCT, UCT) were investigated. The thread engagement length was 2xd. While bolting until failure, forming torque T_F, clamping load at 20 Nm (F_{Cl20Nm}) tightening torque, clamping load at $F_{Cl20Nm+80°}$, clamping loads at bolt rupture F_{br} and tear-off angle ($\alpha_{Tear-off}$) were measured. $\alpha_{Tear-off}$ is defined as the angle measured between the threshold torque of 20 Nm and failure. Both heat treatment conditions were provided out of the same material lot. Figure 3 shows the influence of the heat treatment condition of the thread forming aluminum bolt EN AW 7075 and the impact of the core hole size on essential characteristics to evaluate the bolt connection.

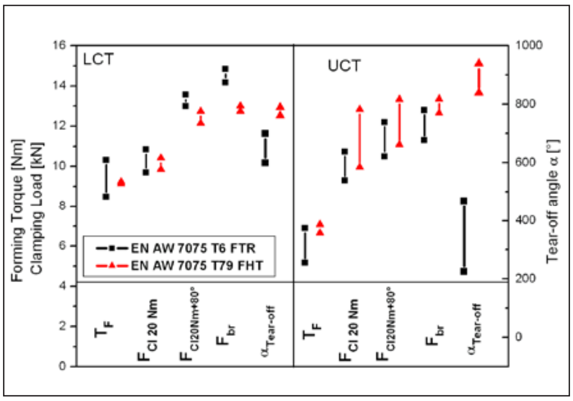

Figure 3. EN AW 7075 in conditions T6 and T79 tightened in AZ91 core holes with minimal and maximum core hole size

It can be seen that the core hole size has a significant impact on the forming torque whereas the effect of the heat treatment condition is negligible. When comparing the bolts T6 and T79 at the lower tolerance limit, it is noticeable that the bolt T6 with maximum strength achieves higher clamping loads when elastic limit is exceeded (20 Nm). However, due to low ductility the tear-off angle is lower compared to the bolt T79.

When considering the bolts at the upper tolerance limit, it is remarkable that despite the lower strength due to overageing, the EN AW 7075 bolt in T79 condition shows clamping forces comparable to the ones of the bolts in T6 condition. Clamping loads at bolt rupture are similar for both conditions, however, the T79 shows a tear-off angle of more than 800° in comparison to 200° of the bolt in condition T6. These results indicate that at the lower core hole tolerance limit, the material strength of the bolt is the essential parameter determining the clamping load whereas at the upper tolerance limit the strength of the Mg nut material is the limiting parameter.

Summarizing, it appears that only condition T79 is suitable for an over-elastic tightening procedure due to two reasons. First, the bolt in T79 achieves comparable or only slightly lower clamping loads to T6 at both investigated tolerance limits. Secondly, the tear-off angle of T79 is remarkably high at the upper as well as at the lower tolerance limit whereas the small tear-off angle of T6 means risk of bolt failure during assembling especially at the upper tolerance limit. However, additional tests with a T6 bolt with final heat treatment should be performed to assess the impact of the final production step on the tightening behavior.

Relaxation

Influence of Mg-alloy

An essential parameter to assess the applicability of the EN AW 7075 thread forming aluminum bolt is the drop in clamping load when an elevated operating temperature is applied. Figure 4 shows the drop in clamping load using EN AW 7075 in T79 condition (FHT), tapped into Mg alloys AZ91 and AE44 at a temperature of 120°C. Over-elastic tightening (20 Nm + 80°) was applied. The length of thread engagement was two times the nominal bolt diameter (2xd). The clamping load was measured with a temperature compensated steel load cell with a nominal force of 40 kN. The pre-cast core holes were at the upper tolerance limit. The low thread coverage causes high local stresses and is thus the critical case as far as creeping and relaxation is concerned.

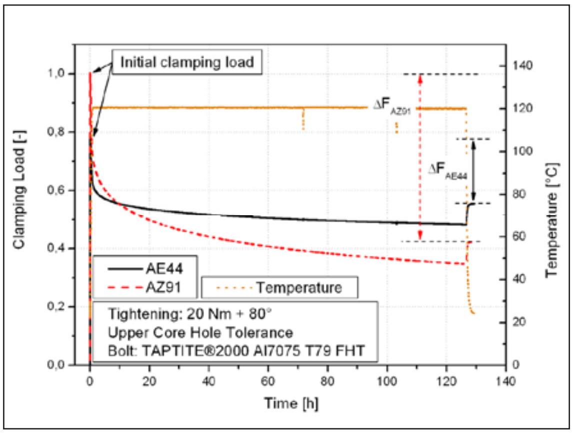

Figure 4. Drop in clamping load at 120°C of AZ91 and AE44 tightened into pre-cast core holes with upper core hole tolerance using EN AW 7075 in T79 condition

Figure 4 reveals that AZ91 reaches higher initial clamping loads in comparison to AE44 due to higher material strength. As a consequence, plastifications at the nut thread flanks during tightening occur earlier in the alloy AE44 and therefore the initial clamping load is only about 80 % of AZ91. However, significantly lower relaxation rates of AE44 lead to higher end values of clamping load after 100 hours. Due to different thermal expansion coefficients of clamping part and bolt, a loss of clamping load during heat-up phase occurs. However, this lost clamping load is regained at the end of the test during cooling down to room temperature.

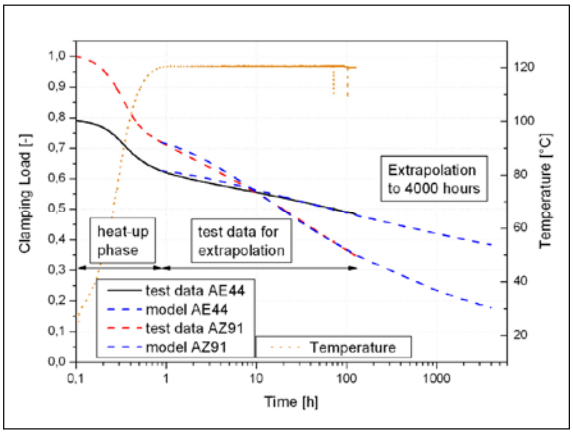

Figure 5. Extrapolation of relaxation test data of AZ91 and AE44 to 4000 hours

The difference in relaxation rate (slope of the tangent) between AZ91 and AE44 can be seen in figure 5. After reaching constant operating temperature of 120°C, the test data were extrapolated to 4000 hours, which is assumed as a components full life time, using a creep model based on Norton. It is worth to mention that AZ91 has only approximately 15 % remaining clamping load, whereas AE44 reveals significantly higher clamping load end values.

Influence of heat treatment condition and production sequence of Al-bolt

To investigate the influence of the heat treatment condition and the production sequence of the aluminum bolt on the relaxation behavior, relaxation tests with four different types of bolts were performed. Core holes at the lower tolerance limit of the alloy MRI153 were used. Both heat treatment conditions T6 and T79 of the bolt EN AW 7075 were tested as final heat treated as well as final thread rolled. The initial clamping load values after tightening as well as the relaxation behavior were investigated. In this case, another T79 FHT with lower yield strength was used.

Figure 6 a and b shows the influence of the material strength of the used Al-bolt on the initial clamping load values with subsequent relaxation behavior. The starting clamping load value rises with increasing yield strength of the bolts (figure 6 a). Consequently, bolts in heat treatment condition T6 exhibit higher initial clamping loads due to higher material strength than T79 bolts. However, T6 bolts reveal worse relaxation resistance than T79, independent from production sequence. Furthermore, bolts with heat treatment as final production step reveal lower relaxation rates in comparison to bolts that are finally thread rolled. As a result, the relative drop in clamping load of the finally heat treated bolts is lower as can be seen in figure 6.

According to [9], M6 EN AW 7075 bolts were examined in tensile tests during temperature exposure and following long-term temperature exposure. The tensile test of EN AW 7075 at elevated temperature of 120°C showed a drop in strength of about 12%. After 1000 hours at 130° temperature exposure and cooling down to room temperature, the drop in strength was about 17%. Therefore [9] assumed that the magnesium alloy causes the greater part of clamping load drop.

Nevertheless, the observed influence of heat treatment condition and production sequence of the Al-bolts on the relaxation behavior is remarkable and needs to be taken into account when designing a light metal bolted joint.

Influence of pulsating service load

Power train components such as gear boxes are exposed to dynamic loads. Clamping load retention trials with superimposed dynamic pulsating loads were conducted. To assess the limits of applicability of aluminum bolts in magnesium joints, high service loads were applied onto the test specimens. High pressure die casted magnesium specimens were bolted with EN AW 7075 – T79 (FHT). A superimposed pulsating load of 2.2 kN mean force and an amplitude of 1.8 kN at load frequency of 12 Hz was applied. The number of stress cycles is approx. 10^6 at a stress ratio of R = 0.1.

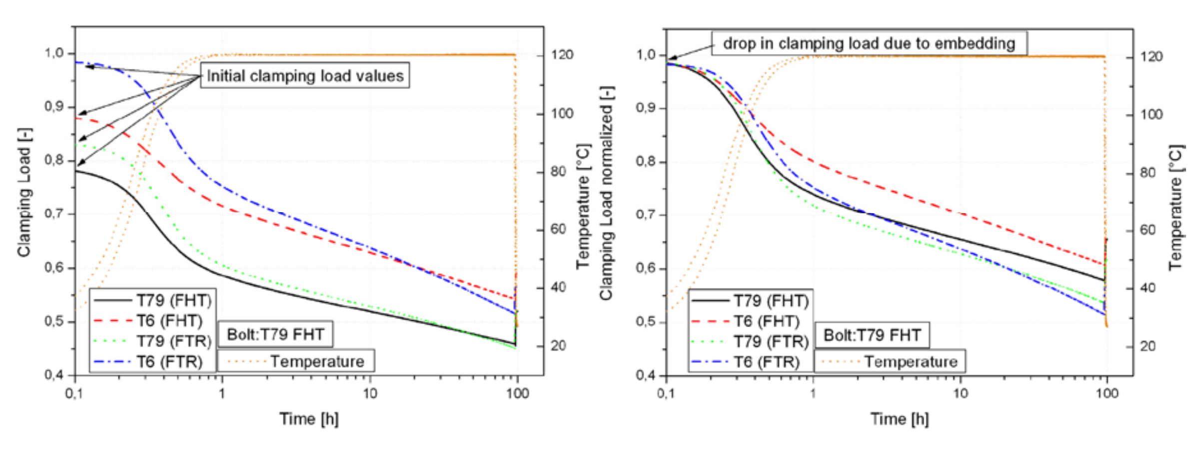

Figure 6. Influence of heat treatment condition and production sequence of EN AW 7075 on drop in clamping load in MRI153 at 120°C (LCT)

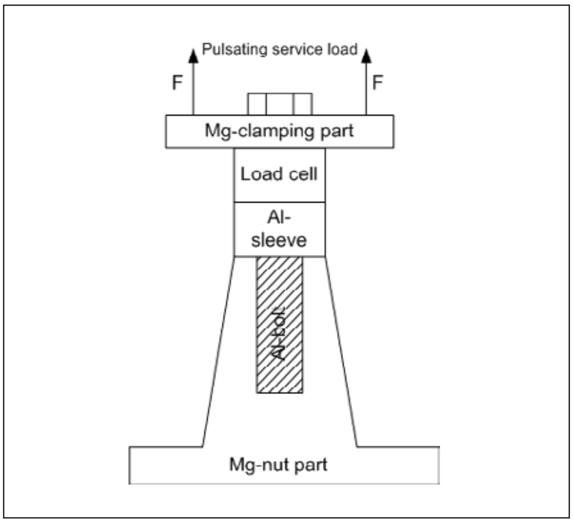

Figure 7. Relaxation test arrangement

The test arrangement for relaxation tests with superimposed pulsating service load consists of a Mg-nut part, a load cell, an aluminum sleeve, a Mg-clamping part and an aluminum bolt (figure 7).

To draw conclusions about the system's behavior without temperature influence, the first trial was conducted at room temperature.

Room Temperature testing

Figure 8 shows the relaxation behavior of the magnesium alloy AE44 with superimposed load in comparison to a static clamping load retention curve. An abrupt drop in the remaining clamping load can be seen when the mean load is applied. The part of the applied service load which is measured by the load cell due to the test arrangement is indicated in figure 8. After applying the pulsating load, no higher relaxation rate in comparison to the specimen loaded only with static clamping force can be observed. At the end of the test the clamping load rises abruptly due to the retraction of the pulsating service load. Summarizing it is possible to conclude that a superimposed external load has no significant impact on the bolt load retention behavior at RT.

Elevated temperature testing

The influence of a superimposed pulsating load at elevated temperatures on the relaxation behavior of a bolted AE44 specimen is shown in figure 9. The critical case of relaxation was considered by testing at upper core hole tolerance. The most significant difference between static and dynamic load cases can be observed during the heating up phase. This can be seen more clearly in logarithmical scale (figure 9 b). After reaching a constant temperature level of 120°C, the specimen with superimposed service load reveals only slightly higher relaxation rates in comparison to the static one.

This high drop in clamping load during the heat-up phase can be explained with plastic deformation of the nut thread flanks due to the superimposed pulsating load. This is intensified by material softening occurring during the heat-up phase.

The trials were also conducted with the alloy AZ91 (figure 10). The observed properties are different to the outcomes of the trials with AE44. The drop in clamping load while heating up occurs to a similar extent

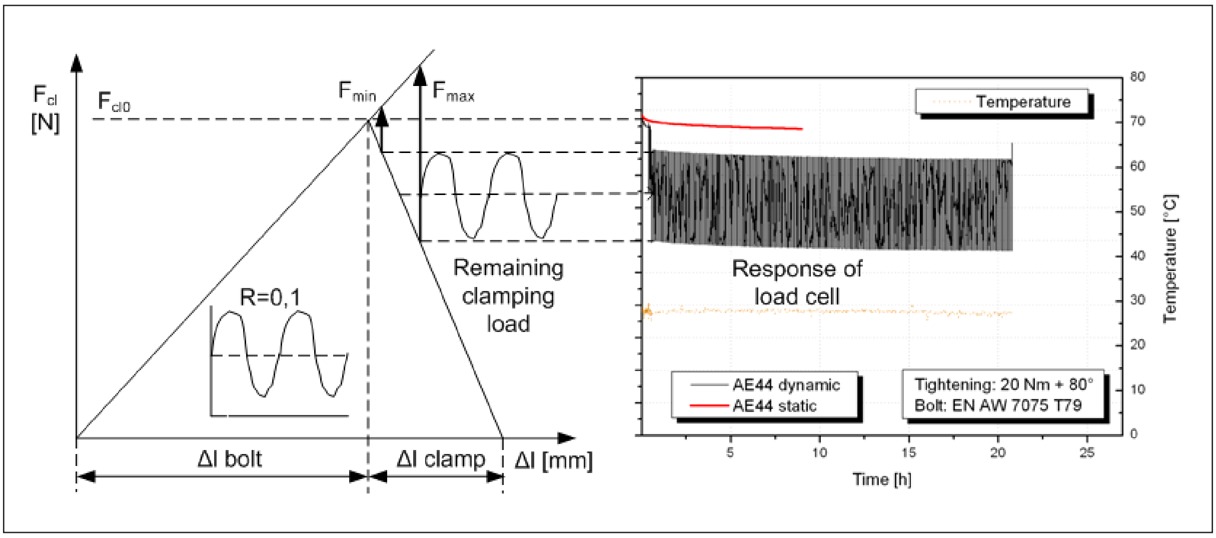

Figure 8. Influence of pulsating service load on drop in clamping load at RT of Mg-alloy AE44 (UCT)

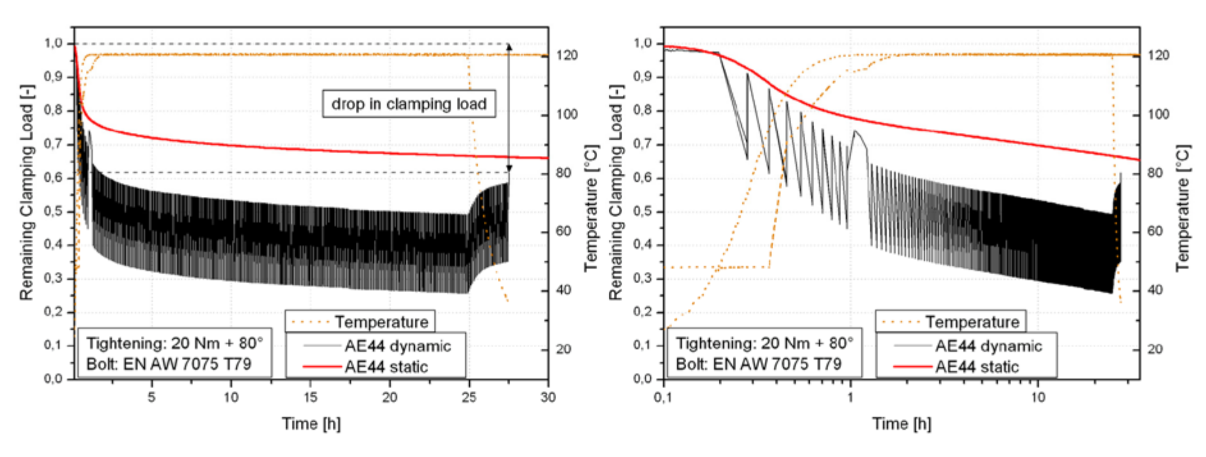

Figure 9. Influence of pulsating service load on drop in clamping load at 120°C of AE44 (UCT) (a); logarithmic scale (b)

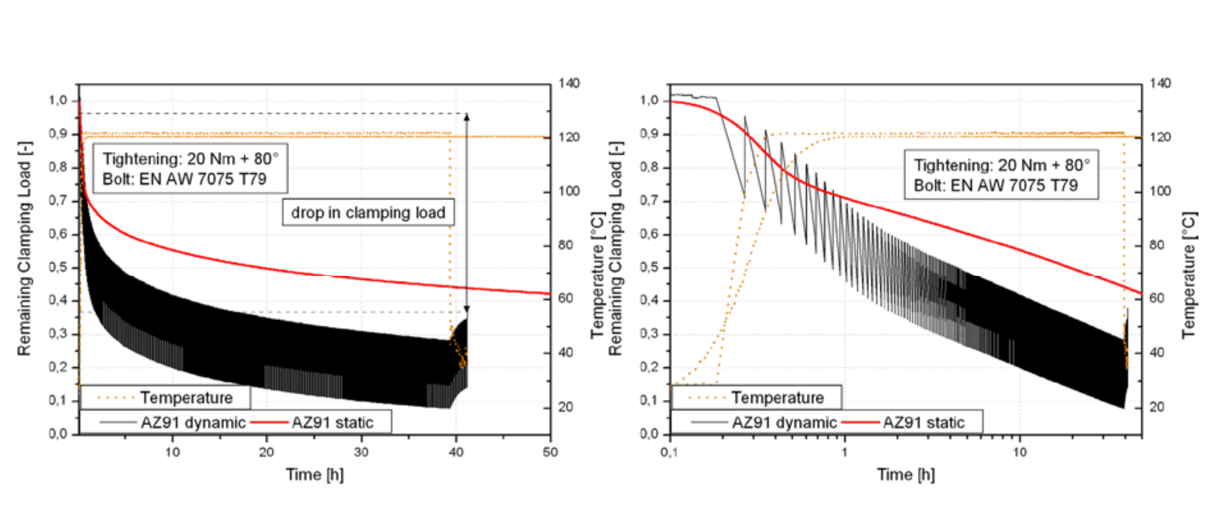

Figure 10. Influence of pulsating service load on drop in clamping load at 120°C of AZ91 (UCT) (a); in logarithmic scale (b)

for both alloys but the relaxation rate of AZ91 after reaching constant temperature is significantly higher in comparison to the static load case. AZ91 exhibits higher relaxation rates and lower clamping load end values than AE44. The drop in clamping load of AZ91 is over 90 % of the initial value whereas AE44 exhibits about 70 %.

Corrosion

Galvanic corrosion

To carry out the contact corrosion assessment, magnesium housings and magnesium flanges in AZ91 were taken and 25 bolt systems differing in bolt material and coating were fastened into them. In the following, some informative results of the comprehensive investigations are presented (table 1). Once tightened up to design torque level, the bolted magnesium housings were subjected to a salt spray test as per ISO 9227:2006 (corrosion tests in artificial atmospheres – salt spray tests) for 720 hours. For this test, steel bolts with zinc flake and galvanic surfaces with and without additional protection systems were used. Protection systems used to shield the bolt heads were aluminum cups or plastic coatings such as electrostatic nylon head coating, as well as various sealing systems covering the entire bolt. Furthermore, uncoated EN AW 7075 and EN AW 6056 aluminum bolts were used.

Test No.	Bolt	Material	Coating	Additional Prot.
1	TT2000 M8	Al-7075	No	No
2	TT2000 M8	Al-6056	No	No
3	Metr. M10	St-9.8	Electropolated	Al cup washer
4	TT2000 M8	St-10.9	Electropolated, thick layer passivated	sealed
5	TT2000 M8	St-10.9	Zinc flake coated	sealed

Table 1: Bolt systems tested in salt spray test for 720 hours

Some of the results of the corrosion tests are shown below. The corrosion products were removed after 720 hours of salt spray test, the maximum depth of corrosion in the AZ91 magnesium cover was measured and longitudinal cuts were made through the joint. Bolts in EN AW 6056 alloy are currently used in the automotive industry to fasten magnesium power train components. Figure 11 shows a M8 EN AW 6056 bolt after 720 hours of salt spray test. Low corrosive attack of the magnesium flange is visible. However, the aluminum bolt exhibits considerable signs of corrosive attack.

The results of the M8 EN AW 7075 bolt after 720 hours of salt spray test is shown in figure 12. Similar corrosion behavior to M8 EN AW 7075 regarding corrosive attack of the magnesium flange and appearance of the bolt is

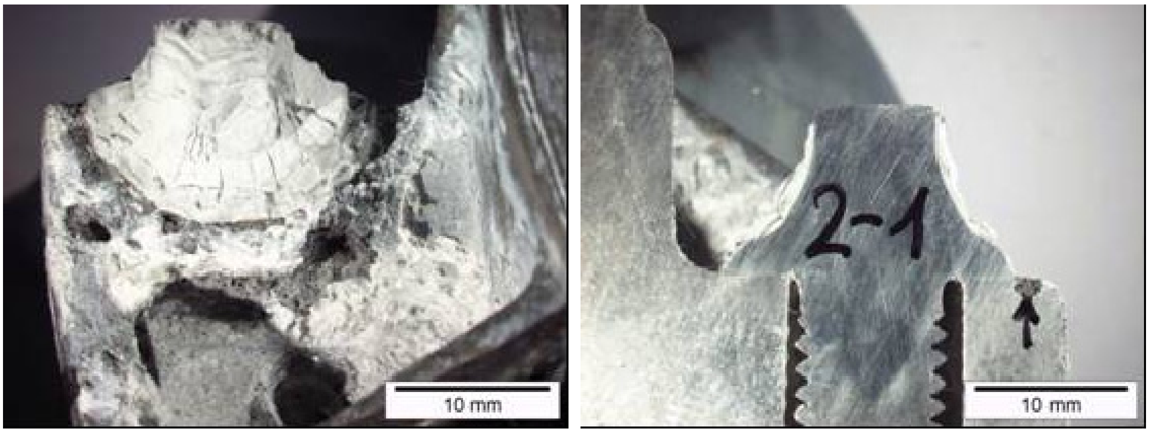

Figure 11. Side view and longitudinal cut of M8 EN AW 6056 after 720 hours of salt spray test

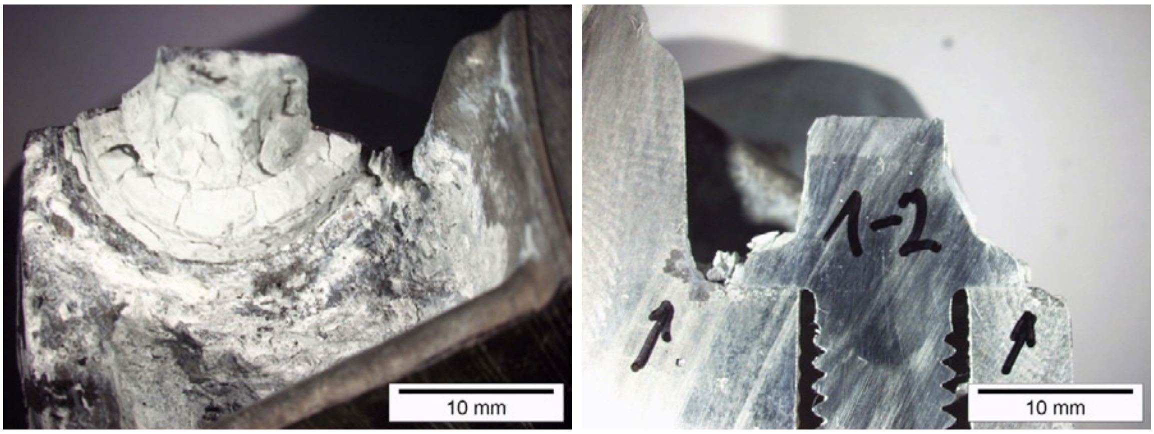

Figure 12. Side view and longitudinal cut of M8 EN AW 7075 after 720 hours of salt spray test

visible. The maximum depth of the corrosive attack in the magnesium flange was in the range of 1 to 3 mm for both types of aluminum bolts (EN AW 6056 and EN AW 7075) and no significant difference could be observed.

The salt spray test was carried out in the same way using steel bolts with differing protection systems. Figure 13 indicates the results after 720 hours using a 9.8 steel bolt with aluminum cup washer. The magnesium flange as well as the steel bolt exhibit only slight corrosive attack. The maximum depth of corrosion in the magnesium flange is between 0.1 and 0.3 mm, the same as for the aluminum bolts. Concerning corrosive attack of mg flange and bolt, this system reveals the best corrosion properties so far.

The 10.9 steel bolt with electroplating, thick layer passivation and seal, shown in figure 14, is already in use in the automotive industry to some degree and is recommended for fasteners that are in contact with magnesium. Maximum corrosion depths in magnesium of 1 to 3 mm occurred after 30 days.

When using 10.9 bolts, zinc flake coated and sealed, maximum corrosion depths in AZ91 magnesium of 3 to 10 mm occurred (figure 15).

With regard to galvanic corrosion, there is no significant difference between the EN AW 6056 and EN AW 7075 aluminum bolts concerning depth of corrosion in the magnesium and the corrosive attack of the bolt after 30 days of salt spray test.

The steel bolts with aluminum cup washer indicated comparable results regarding depth of corrosion in the magnesium flange to the investigated aluminum bolts. However, the steel bolts exhibited less corrosive attack in comparison to the aluminum bolts.

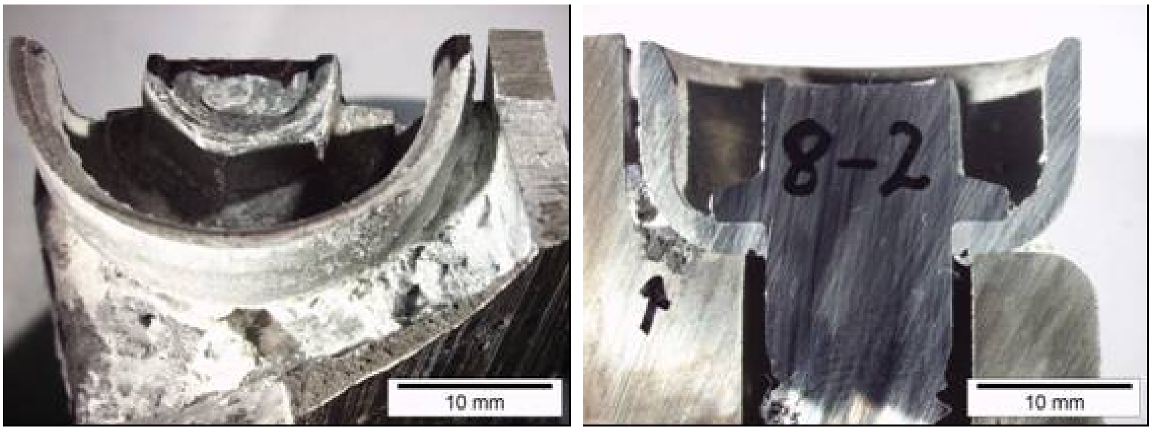

Figure 13. Side view and longitudinal cut of 9.8 steel bolt, electroplated with Al cup washer after 720 hours salt spray test

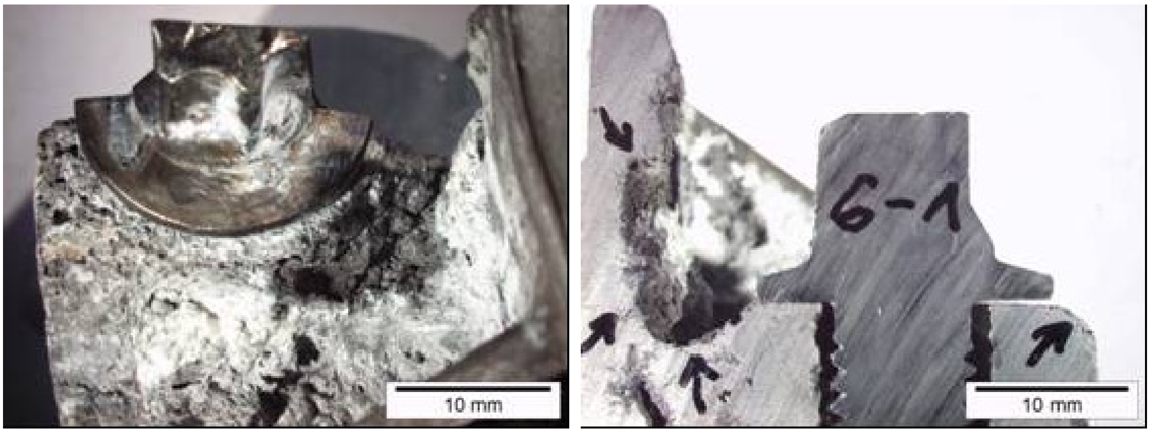

Figure 14. Side view and longitudinal cut of 10.9 steel bolt, electroplated, thick layer-passivated and sealed after 720 hours salt spray test

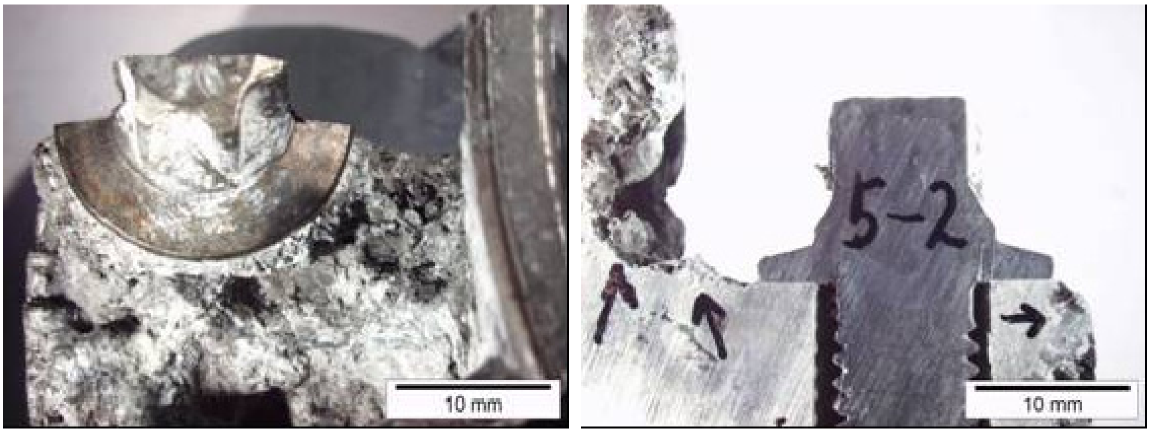

Figure 15. Side view and longitudinal cut of 10.9 steel bolt, zinc flake coated and sealed after 720 hours salt spray test

When using steel bolts without aluminum cup washer, strong corrosion of the magnesium flange was visible. Those that were electroplated, thick-layer passivated and sealed indicated slightly lower corrosion depth in the magnesium than the steel bolts with zinc flake coating and seal.

An electrostatic nylon head coating achieves an improvement concerning corrosion in the magnesium flange. However, the depth of corrosion in the magnesium is still significantly higher compared to using aluminum bolts.

As far as galvanic corrosion for magnesium bolted joints in exposed mounting positions is concerned, either the aluminum bolts (EN AW 6056 and EN AW 7075) or the steel bolts with aluminum cup are applicable.

Stress crack corrosion

Stress crack corrosion tests were performed on M8 EN AW 7075 alloy aluminum bolts. In literature, the EN AW 7075 in T6 condition is generally considered to be at risk of stress crack corrosion. This potential risk was confirmed in [9]. Within that project EN AW 7075 T6 bolts were screwed into a steel pipe construction. This bolt assembly was then subjected to the VDA (Verband der Automobilindustrie) alternating atmosphere test (5 cycles: 1 cycle of 24 hours salt spray test, and 4 x 8 hours of condensate water, 16 hours of normal atmosphere, and 48 hours normal atmosphere). In comparison, in the same test structure, bolts produced under T79 and T73 heat treatment conditions did not fail due to stress crack corrosion.

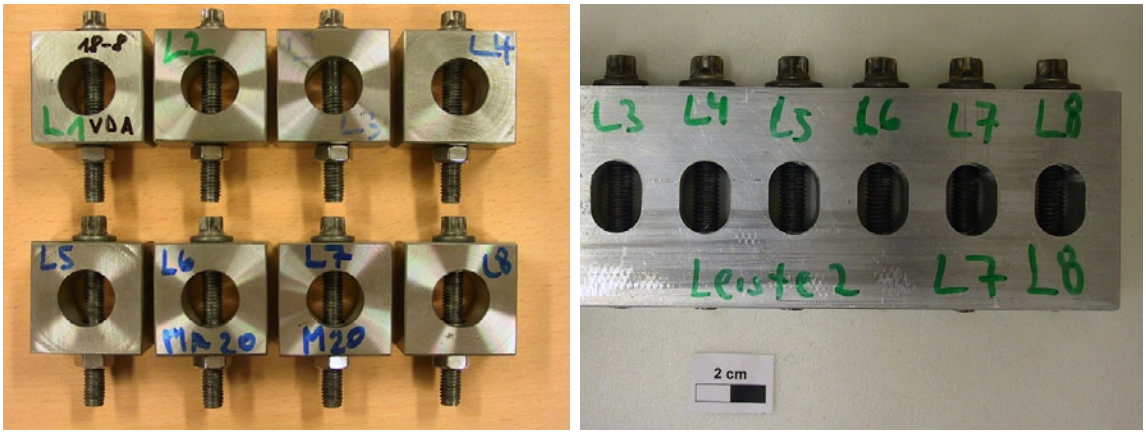

Figure 16. Bolted joints for stress crack corrosion and galvanic corrosion testing

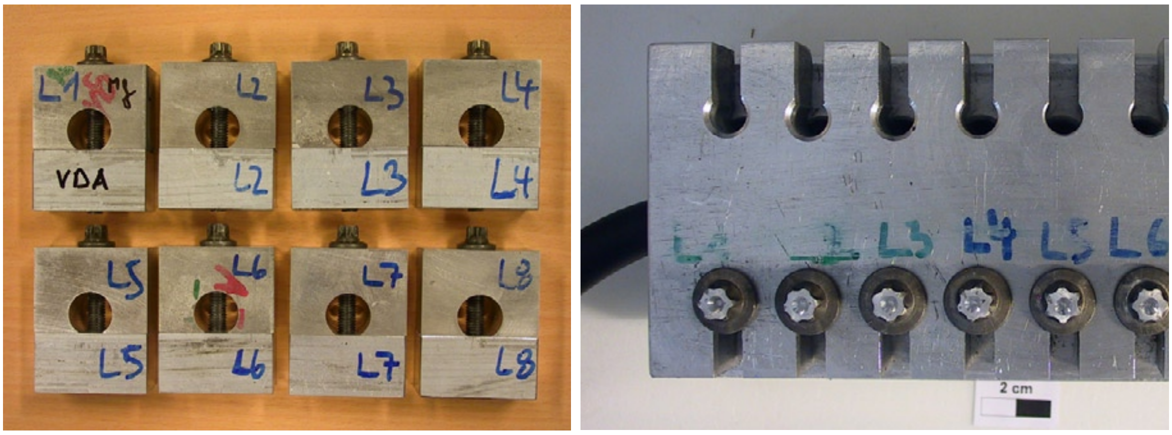

Figure 17. Bolted joints for stress crack corrosion testing

As part of this research project, the trials documented in the bibliography were first verified and then further investigations were carried out. The following test structures were used:

- Stainless steel clamping component with stainless steel nut and EN AW 7075 T6 aluminum bolt – alternating atmosphere test as per VDA 621-415 [10], duration: 5 cycles (fig 16)
- AlMgSi0.5 aluminum clamping and nut component with cut thread and EN AW 7075 T6 bolt – alternating atmosphere test as per VDA 621-415, duration: 5 cycles (fig 16)
- AlMgSi0.5 aluminum clamping and nut component with cut thread and EN AW 7075 T6 bolt – ISO 9227:2006 salt spray test (SST), duration: 720 hours (fig 16)
- Magnesium clamping part with AlMgSi0.5 nut component with cut thread and EN AW 7075 T6 bolt – alternating atmosphere test as per VDA 621-415, duration: 5 cycles (fig 17)
- AlMgSi0.5 clamping part and nut part with cut thread and EN AW 7075 T6 bolt – 3% NaCl solution a temperature of 80 °C flushed over clamped bolt body, duration: 720 hours (fig 17)

In these investigations EN AW 7075 T6 bolts broke as a result of stress crack corrosion only in the set-up consisting of stainless steel clamping component with stainless steel nut in the VDA 621-415 [10] alternating atmosphere test, from the third cycle onwards. This means that stress crack corrosion is enhanced considerably by the anodic decomposition of the bolt and not by cathodic processes such as hydrogen absorption and subsequent embrittlement. No failures were recorded in the Al-Mg structure which is most representative for the investigated application.

Conclusion

Based on the investigations carried out it is possible to draw the following conclusions:

- Both the EN AW 7075 T6 and the EN AW 7075 T79 meet the rigidity requirements for forming threads into pre-cast AZ91, AE44 und MRI153 core holes.
- The EN AW 7075 in heat treatment condition T79 reveals sufficient elongation reserves for over-elastic tightening.
- At a temperature of 120 °C the Mg-alloy AE44 shows significant better relaxation properties, meaning lower relaxation rates and thus higher remaining clamping loads compared to AZ91.
- When using the EN AW 7075 T79 the drop in clamping load is less than in T6 condition.
- EN AW 7075 with heat treatment as final production step exhibit lower relaxation rates than the ones that are finally thread rolled.
- The material strength of the bolt influences determines the clamping load level at the lower tolerance limit whereas at the upper limit the Mg nut material strength is the essential parameter.
- Superimposed pulsating service loads at 120°C cause only slightly higher relaxation rates in comparison to static relaxation behavior when Mg-alloy AE44 is used. With AZ91operating loads cause a significant deterioration in relaxation behavior.
- The EN AW 7075 is equal to the bolt EN AW 606 regarding galvanic corrosion under the investigated conditions.
- Aluminum bolts show better corrosion behavior than steel bolts in combination with Mg nut materials. Only steel bolts with aluminum cups show similar corrosion behavior to aluminum bolts.

- The thread forming bolt EN AW 7075 T79 can be classified as uncritical with regard to stress crack corrosion for the tested condition which are typical for automotive applications.

Outlook

Currently prototypes of a transfer case are being built up. The alloys AZ91 and AE44 are used as housing materials, the transfer cases are bolted together with EN AW 7075 T79 M8x35 thread forming bolts. The prototypes will be subjected to torsion fatigue testing. Furthermore, the relaxation behavior under service condition will be investigated.

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