DE GRUYTER OPEN

DOI: 10.1515/aucts-2017-0007

ACTA UIVERSITATIS CIBINIENSIS – TECHNICAL SERIES
Vol. LXIX 2017

FATIGUE ANALYSIS OF MAGNESIUM ALLOYS COMPONENTS FOR CAR INDUSTRY

MARSAVINA Liviu
Professor, Faculty of Mechanical Engineering/Department of Mechanics and Strength of Materials, University Politehnica Timișoara, Timișoara, Romania, liviu.marsavina@upt.ro

RUSU Lucian
Lecturer, Faculty of Mechanical Engineering/Department of Mechanics and Strength of Materials, University Politehnica Timișoara, Timișoara, Romania, lucian.rusu@upt.ro

ȘERBAN Dan Andrei
Lecturer, Faculty of Mechanical Engineering/Department of Mechanics and Strength of Materials, University Politehnica Timișoara, Timișoara, Romania, dan.serban@upt.ro

NEGRU Radu Marcel
Lecturer, Faculty of Mechanical Engineering/Department of Mechanics and Strength of Materials, University Politehnica Timișoara, Timișoara, Romania, radu.negru@upt.ro

CERNESCU Anghel
Lecturer, Faculty of Mechanical Engineering/Department of Mechanics and Strength of Materials, University Politehnica Timișoara, Timișoara, Romania, anghel.cernescu@upt.ro

Abstract: *The use of magnesium alloys in the automotive industry increased in the last decade because of their low weight and relative good mechanical properties. However, the variable loading conditions require a good fatigue behavior. This paper summaries the fatigue properties of magnesium alloys and presents new fatigue curve results for die cast AM50 magnesium alloy.*

Key words: magnesium alloy, fatigue curve, steering wheel

1. Introduction

Magnesium alloys are suitable for the automotive industry, because they are lighter than steel and aluminum alloys, and they have relative good mechanical and fatigue properties. Die casted Magnesium alloy AM50 represents one of the preferred magnesium alloys for steering wheel, housing, engine cradle, [1,2]. However, the die-cast products inhere a variety of casting defects such as porosity, oxide films and intermetallic particles, which are harmful to the mechanical properties, in particular, the fatigue behavior. It has been reported that fatigue-crack nucleation in a cast AM60B is mainly caused by porosity [3 - 6]. Fatigue lives of the die-cast AM60B alloy could be successfully predicted by the fracture mechanics approach, where the pore at crack initiation site was assumed as the pre-existing crack. This clearly suggests that scatter behavior of fatigue life would be mainly caused by the scatter of pore size [7].

Both low cycle fatigue [8] for AZ31, [9] for AZ 91 HP, AM 50 HP and AM 20 HP, Patel et al. for AM60 [10], respectively high cycle fatigue [7,11] for AM60 approaches were employed for durability studies of Magnesium alloys.

This paper presents the mechanical and fatigue properties of AM50 magnesium alloy, and a durability prediction for a steering wheel, based on material data obtained experimentally.

2. Static properties of Magnesium alloy

AM50 magnesium alloy specimens were manufactured, by die-casting in the same manufacturing conditions as steering wheels in a special mold. The resulting specimens are shown in Fig. 1. The chemical composition of investigated Mg alloy is presented in Table 1, and this assure high ductility and very good properties for energy absorption.

DE GRUYTER OPEN

DOI: 10.1515/aucts-2017-0007

ACTA UIVERSITATIS CIBINIENSIS – TECHNICAL SERIES
Vol. LXIX 2017

Table 1 Chemical composition of the investigated Mg alloy

Material	Aluminum [%]	Manganese [%]	Zinc [%]	Iron [%]	Nickel [%]

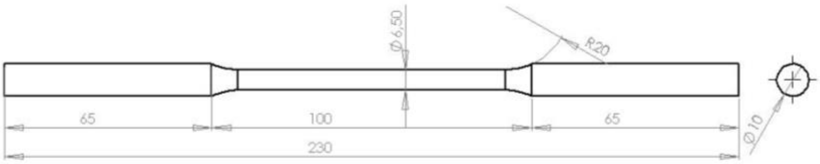


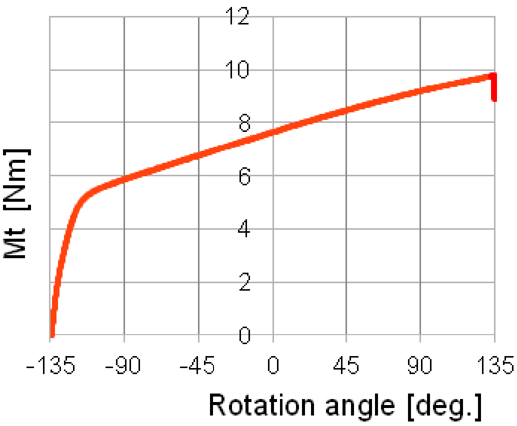
Figure 1: AM50 specimens obtained by die-casting **Figure 2: Cylindrical specimen**

Tensile and torsion tests were performed on cylindrical specimens. Tests were performed on Instron static and dynamic testing machine with amaximum load of 25 kN, at room temperature. The strain was recorded using a video-extensometer. Tensile tests were carried on according to [12], the yield stress was determined at 0.2% strain. Typical stress - strain curve obtained in tension is shown in Fig. 3.a. A linear elastic region followed by an elasto-plastic domain with hardening can be observed. The mean values of the mechanical properties in tension are presented in Table 2. The obtained values are in agreement with those from literature apart from the Young modulus which is 19.6% smaller, the yield stress is 1.8% smaller and tensile strength is higher with 3 %, while the strain at break is lower with 3.4%.
The curve depicting the torsion moment versus deformation angle is plotted in Fig. 3.b. The behavior is similar to that in tension: a linear elastic part, followed by a linear hardening behavior. The mean value of the ultimate shear stress is 172 MPa, resulting in a ratio between maximum shear stress and ultimate tensile strength of 0.66.

Table 2 Tensile properties of the investigated Mg alloy

Material	Young modulus [MPa]	Tensile strength [MPa]	Yield stress [MPa]	Strain at break [%]
AM50 from tests	37625	236.9	122.8	14.5
AM50 from [7, 8]	45000	230	125	15

a. Tensile b. Torsion



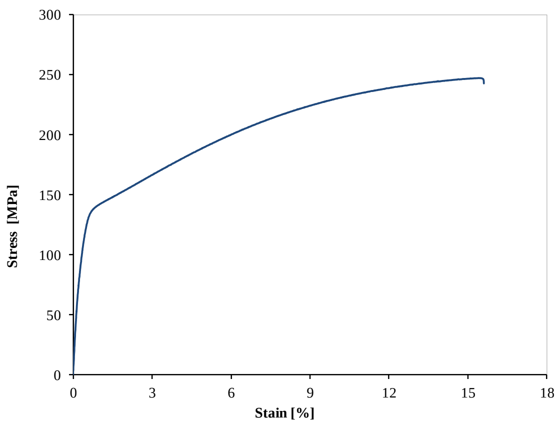


Figure 3: Typical stress - strain curves

3. Fatigue properties of Magnesium alloy

The required durability of steering wheels is in the range of medium cycle fatigue: $2x10^5$ to $1x10^6$ cycles. The fatigue tests were performed under load

DE GRUYTER
OPEN

DOI: 10.1515/aucts-2017-0007

ACTA UIVERSITATIS CIBINIENSIS – TECHNICAL SERIES
Vol. LXIX 2017

control, at room temperature using an R-ratio of 0.1, using Instron static and dynamic testing machine with a maximum load of 25 kN. Two tests were performed at each load level. Specimens which did not fail up to $1x10^6$ cycles were stopped (represented with → in Fig. 4). The maximum load corresponding to a durability of $1x10^6$ cycles is 62.5 MPa. For a die-cast AM60 Magnesium alloy in [7] the fatigue limit for three point bending is 73.8 MPa.

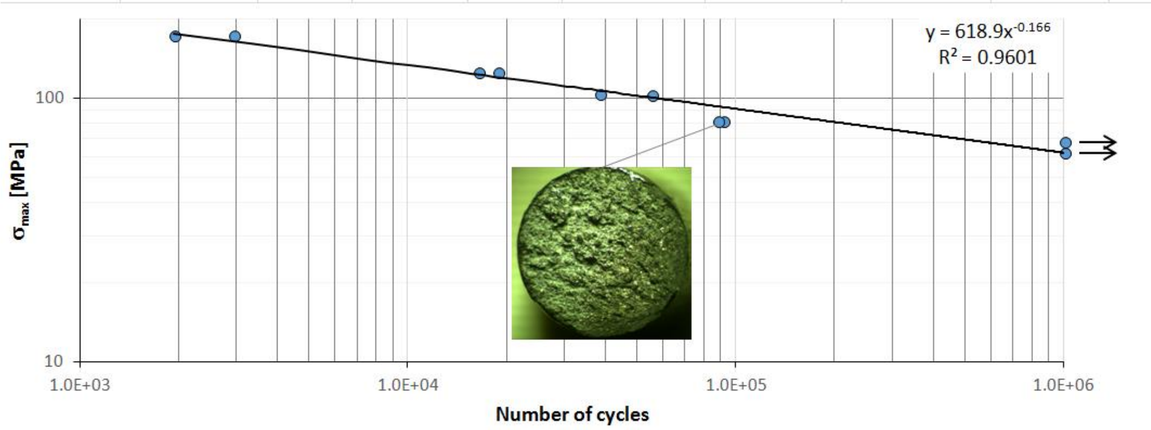
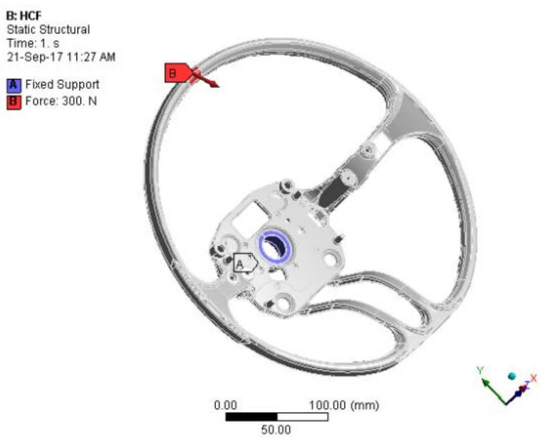


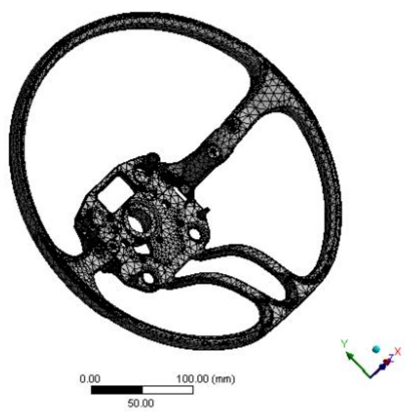
Figure 4: Experimentally determined fatigue curve for AM50 Magnesium alloy

The obtained fatigue strength σ_f at $1x10^6$ represents 30% from the tensile strength σ_r, which is in agreement with the empirical relationship between fatigue strength and tensile strength of Li et. al. [11]: $\sigma_f = (0.25\text{-}0.50)\ \sigma_r$.

4. Numerical estimation of durability for car steering wheel

The numerical simulations were performed in fatigue testing conditions on the steering wheel [13], using ANSYS Workbench. The mechanical and fatigue properties were defined as the ones determined experimentally in static and fatigue tests. The geometry of the steering wheel was generated in CATIA and imported. The boundary conditions were imposed according with [13] gripping the bottom part, and applying a 300 N load, Fig. 5.a. The steering wheel was meshed with 104888 SOLID187 elements connected in 176294 nodes, Fig. 5.b. The results of the static analysis are shown in Fig. 6. The maximum total displacement 6.6 mm was obtained on the point of applied load as we expected (Fig. 6.a), the maximum equivalent stress 98 MPa was obtained in one of the bottom holes (Fig. 6.b) and is lower than the yield stress of the Mg alloy 122.8 MPa, validating the strength static condition.





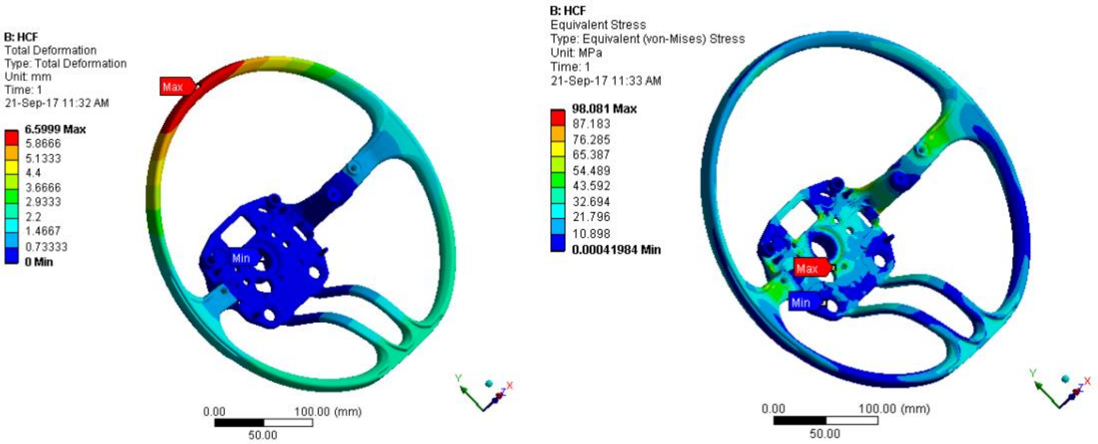
DE GRUYTER
OPEN

DOI: 10.1515/aucts-2017-0007

ACTA UIVERSITATIS CIBINIENSIS – TECHNICAL SERIES
Vol. LXIX 2017

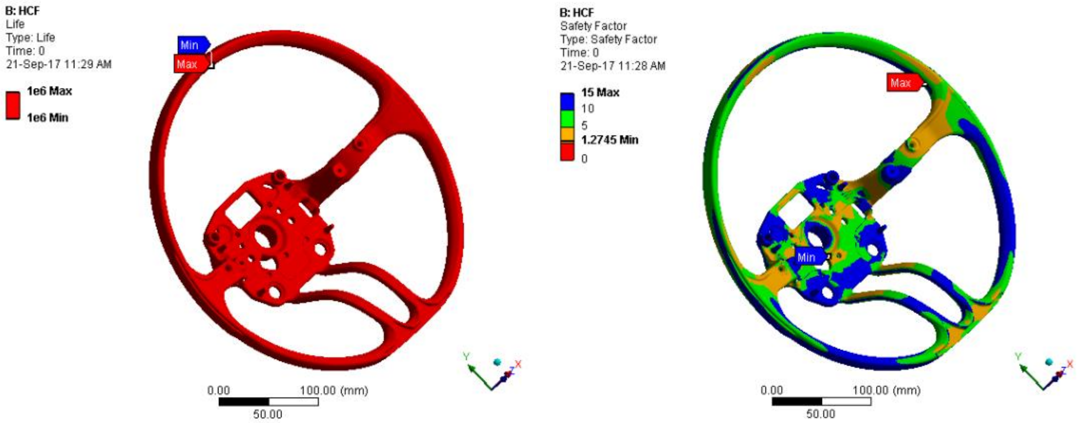
a. Boundary conditions b. Mesh

Figure 5: Problem set-up



a. Total deformation b. Von Mises equivalent stress

Figure 6: Static analysis results



a. Safety factor b. Life

Figure 7: Fatigue analysis results

The fatigue analysis was performed for R = 0 and without considering the mean stress effect. Having determined the fatigue curve on specimens manufactured in the same conditions as the steering wheel, the fatigue coefficient is $K_f = 1$. The fatigue results indicate that the minimum safety factor is 1.274 and the durability equals 10^6 cycles.

5. Conclusions

The mechanical properties of AM50 magnesium alloy were obtained by tensile and torsion testing and they are in good agreement with those from literature. The tests were performed on die-casted specimens manufactured in the same conditions like the steering wheels.

The S-N curve was plotted for tensile tests, with R=0.1,the fatigue limit at the durability of 10^6 cycles being 62.5 MPa.

The fatigue curve was used for durability estimation of a steering wheel manufactured from AM40 magnesium alloy, the numerical analysis showing a safety factor of 1.274, respectively a 10^6 cycles durability.

DE GRUYTER
OPEN

DOI: 10.1515/aucts-2017-0007

ACTA UIVERSITATIS CIBINIENSIS – TECHNICAL SERIES
Vol. LXIX 2017

6. Acknowledgements

This work was supported by the UEFISCDI, Romania under Bridge Grant program, grant no. BG89/2016.

7. References

1. Friedrich, H, Schumann, S, Research for a "new age of magnesium" in automotive industry. *J. Mater. Proc. Technol.*, Vol. 117, pp. 276-281, (2001).
2. Friedrich H. E., Mordike B. L. *Magnesium Technology–Metallurgy, Design Data, Applications*. Springer, 93, (2006).
3. Rittel D., Wang Z.G., Thermo-mechanical aspects of adiabatic shear failure of AM50 and Ti6Al4V alloys, *Mechanics of Materials*, Vol. 40, pp. 629–635, (2008).
4. Lu Y, Taheri F, Gharghouri MA, Han HP. Experimental and numerical study of the effects of porosity on fatigue crack initiation of HPDC magnesium AM60B alloy, *J Alloy Compd*, Vol. 470, pp. 202–13 (2008).
5. Horstemeyer MF, Yang N, Gall K, McDowell D, Fan J, Gullet PM. High cycle fatigue mechanisms in a cast AM60B magnesium alloy, *Fatigue Fract Eng Mater Struct*, Vol. 25, pp. 45–56, (2002).
6. Ding, H.-L., Zhang, Y.-W., Kamado, S., Effect of finish-rolling conditions on mechanical properties and texture characteristics of AM50 alloy sheet, *Trans. Nonferrous Met. Soc. China*, Vol. 24, pp. 2761-2766, (2014).
7. Mohd S., Mutoh Y., Otsuka Y., Miyashita Y., Koike T., Suzuki T., Scatter analysis of fatigue life and pore size data of die-cast AM60B magnesium alloy, *Eng Failure Analysis*, Vol. 22, pp. 64–72, (2012).
8. Begum S., Chen D.L., Xub S., Luo A. A., Low cycle fatigue properties of an extruded AZ31 magnesium alloy, *International Journal of Fatigue*, Vol. 31, pp. 726–735, (2009).
9. Sonsino C.M., Dieterich K., Fatigue design with cast magnesium alloys under constant and variable amplitude loading, *International Journal of Fatigue*, Vol. 28, pp. 183-193, (2006).
10. Patel H.A., Chen D.L., Bhole S.D., Sadayappan K., Low cycle fatigue behavior of a semi-solid processed AM60B magnesium alloy, *Materials and Design*, Vol. 49, pp. 456–464, (2013).
11. Li Z., Wang Q., Luo A.A., Fu P., Peng L., Fatigue strength dependence on the ultimate tensile strength and hardness in magnesium alloys, *International Journal of Fatigue*, Vol. 80, pp. 468–476, (2015).
12. ASTM B557M-02. Standard Test Methods of Tension Testing Wrought and cast Aluminum and Magnesium Alloy Products, ASTM International, (2002).
13. *** Arbeitsaweisung fur Dynamiche Abstutzkrafte, 2014