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Evaluation of fatigue behaviour of magnesium welded joints using energy methods according to Neuber's method

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ABSTRACT

Purpose: When engineering designs that are subjected to cyclic loads are concerned, determining the fatigue behaviour of the components is very important. Thus methods that can evaluate the fatigue behaviour accurately are required. Welded joints that are widely used in engineering constructions are often subjected to cyclic loads and require a method that considers weld geometry and notch effect of the weld toe. Due to their high specific strength and low density, magnesium and its alloys became even more prominent in recent years, allow light and durable designs. Thus evaluating the fatigue behaviour of magnesium alloys for fields of application where weights of designs are a prominent factor is especially important. Therefore researching the fatigue behaviour of welded joints of the magnesium alloys is equally important.

Design/methodology/approach: In this study, conservative Neuber method that is the basis for energy methods is used to evaluate the fatigue behaviour of the magnesium welded joints. Calculations for different weld-like specimen and different stress ratios have been carried out using Neuber method.

Findings: In this study applicability of Neuber's method to evaluate the fatigue behaviour of magnesium welded joints is researched. According to the findings of this study Neuber's method which is a basis for energy based methods are feasible to use for fatigue evaluation of magnesium welded joints.

Research limitations/implications: Although Nueber's method serves as a foundation for energy based methods, it is known to be conservative in its calculations. This research can be expanded by the usage of state of the art energy methods and more accurate findings can be acquired.

Originality/value: Fatigue behaviour of magnesium welded joints have not been evaluated using energy methods before. This novel approach can improve designs against fatigue.

Keywords: Properties; Fatigue; Magnesium; Energy methods; Welded joints

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PROPERTIES

1. Introduction

Most of the mechanical components are subjected to the cyclic loads. Even though the maximum stress caused by these varied loads are less than the strength of the material of the component, if the number of cycles these loads are applied reaches a certain value, sudden structural failures occur on the components. This common phenomenon is named fatigue.

Fatigue can occur anywhere under the effects of cyclic loads and many structural components are subjected to cyclic loads during their service life. Because of this, design against fatigue is important for almost all fields of engineering.

Fatigue damage occurs as cracks that propagate through the material under cyclic loads. The aforementioned sudden failures are caused by these cracks that lower the strength of the material. Detecting the crack initiation by simple observation is quite hard and usually cracks are not discovered until the structural component becomes unusable. Therefore detecting the fatigue life of components during the design process lowers the risk unexpected failures significantly. For this reason, reliable methods that can estimate the fatigue life of mechanical components are required.

Due to the common usage of welding in manufacturing, investigation of fatigue properties of welded joints is invaluable. Inherent notches of the welded joints and changes in material properties due to high temperatures, increases both the difficulty and the importance of determining the fatigue behaviour of welded components In order to accurately determine the fatigue behaviour, a method that can take weld geometry, material properties and loading conditions into account is needed.

By evaluating the fatigue behaviour of the mechanical components using energy methods, a correlation between the damage accumulation and stress is established. The dissipating energy can be used as a physical parameter that shows the behaviour of the material under varied loading.

Neuber's method describes an energy equivalence between the elastic and the elasto-plastic calculations of the same geometry subjected to same loading conditions. This method has many uses in engineering calculations and it is considered a basis for energy methods that are used to determine the fatigue behaviour of materials. The original Neuber's method has been extended to cover various loading conditions and have been studied thoroughly by various scientist with numerous new version propositions in order to fit the engineering needs [1-3].

The stress values calculated using the Neuber's method are considered conservative. However, it is still valuable to re-evaluate the original method using relatively new experimental data. In this study, data acquired from fatigue tests performed on magnesium specimens produced to simulate weld conditions with different material states, have been used in order to present the viability of Neuber's method.

2. Neuber's method

According to Neuber's suggestions, a relation can be established between elastik stress concentration factor, stress concentration factor and strain concentration factor on the notch root that is subjected to plastic deformation. According to this relation elastic stress concentration factor is the geometric average of stress concentration factor and strain concentration factor as shown in the equation (1) [4].

$$K_t = \sqrt{K_\sigma K_\varepsilon} \qquad (1)$$

Stress concentration factor and strain concentration factor can be defined as:

$$nd \quad K_\varepsilon = \frac{\varepsilon}{e}$$

where K_t is elastic stress concentration factor, K_σ is stress concentration factor, K_ε strain concentration factor, σ is elasto-plastic stress, ε is elasto-plastic strain, S is nominal stress and e is nominal strain.

When equation (1) rearranged by replacing K_σ and K_ε, equation (2) is acquired:

$$K_t = \sqrt{\frac{\sigma}{S}\frac{\varepsilon}{e}}$$

$$K_t = \sqrt{\frac{\sigma}{S}\frac{\varepsilon E}{S}}$$

$$K_t^2 = \frac{\sigma\varepsilon E}{S^2}$$

$$(K_t S)^2 = \sigma\varepsilon E \qquad (2)$$

Using the Ramberg-Osgood relationship, equation (2) can be rewritten as following:

$$\varepsilon = \frac{\sigma}{E} + \left(\frac{\sigma}{K}\right)^{\frac{1}{n}} \qquad (3)$$

where E is Young modulus, K is strength coefficient and n is cyclic strain hardening exponent. By replacing ε in equation (2) using equation (3), following equation has been obtained:

$$\frac{(K_tS)^2}{E} = \frac{\sigma^2}{E} + \sigma\left(\frac{\sigma}{K}\right)^{\frac{1}{n}} \qquad (4)$$

In order to be able to use this equation for cyclic loading conditions, stresses are replaced by stress amplitudes and cyclic material parameters are used instead. Rearranged equation has been presented below:

$$K_t\frac{\Delta S}{2} = \sqrt{\left(\frac{\Delta\sigma}{2}\right)^2 + E\frac{\Delta\sigma}{2}\left(\frac{\Delta\sigma}{2K'}\right)^{\frac{1}{n'}}} \qquad (5)$$

where K′ is cyclic strength coefficient and n′ is cyclic strain hardening exponent.

Neuber's rule is a well established method used for notch stress and strains in engineering calculations. However, it is known that the stress values calculated using Neuber's rule are conservative [5]. This should be taken into account when this method is used to evaluate the fatigue behaviour of structural components.

3. Experimental data

Experimental data used in this study acquired from fatigue tests performed on AZ31 magnesium specimens processed to simulate welding. Experiments were performed on three different material groups that correlate to base metal, weld metal and heat affected zone and each subjected to two different stress ratios (R=1, R=0). Each specimen are notched with a stress concentration factor of K_t=11.2. The details of the fatigue tests can be found in [6,7].

Elasto-plastic material data of each material state, relevant to this study has been presented in Table 1.

Table 1.
Elasto-plastic material data according to material states [6,7]

Elasto-plastic Material Data	Material State		
	Base Material	Weld Metal	HAZ
Cyclic strain hardening exponent n′	0.073	0.193	0.161
Cyclic strength coefficient K′ [MPa]	317	428	615
Young modulus E [GPa]	44	44	43

4. Numerical basis

Experimental data along with material parameters presented in Table 3.1 have been used in equation (5) in order to calculate the stress amplitudes in notch root ($\frac{\Delta\sigma}{2}$) for each material state and their stress ratio. Then calculated stress amplitudes are correlated to the number of cycles to failure. For each instance a stress amplitude-number of cycles curve has been plotted and presented in Fig. (1-6).

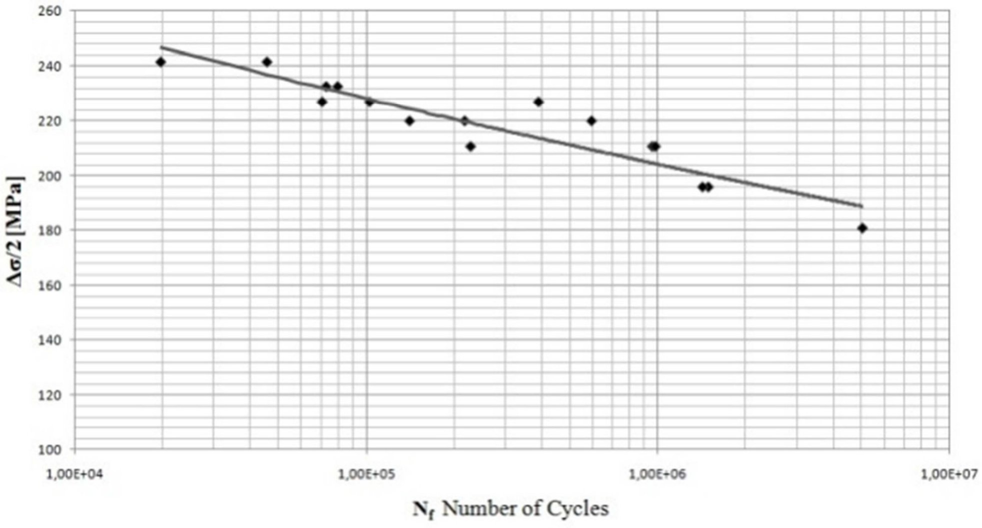

Fig. 1. Wöhler curve for base material (R = -1)

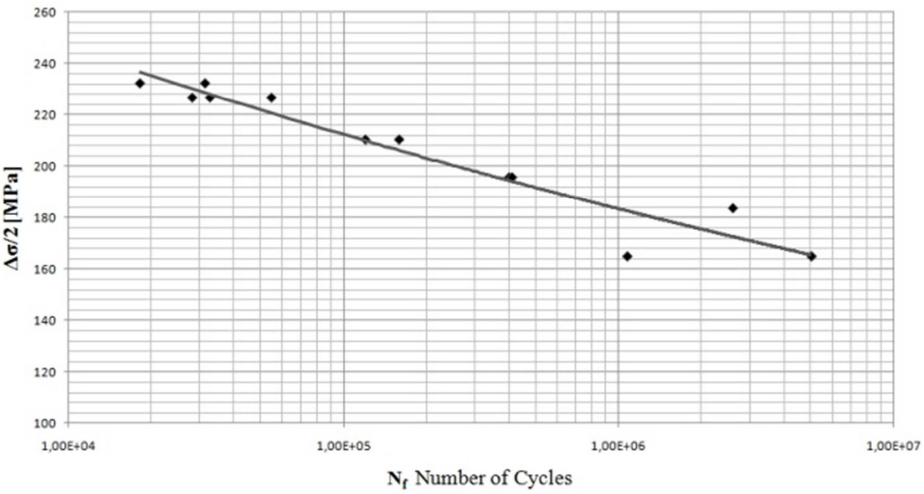

Fig. 2. Wöhler curve for base material (R = 0)

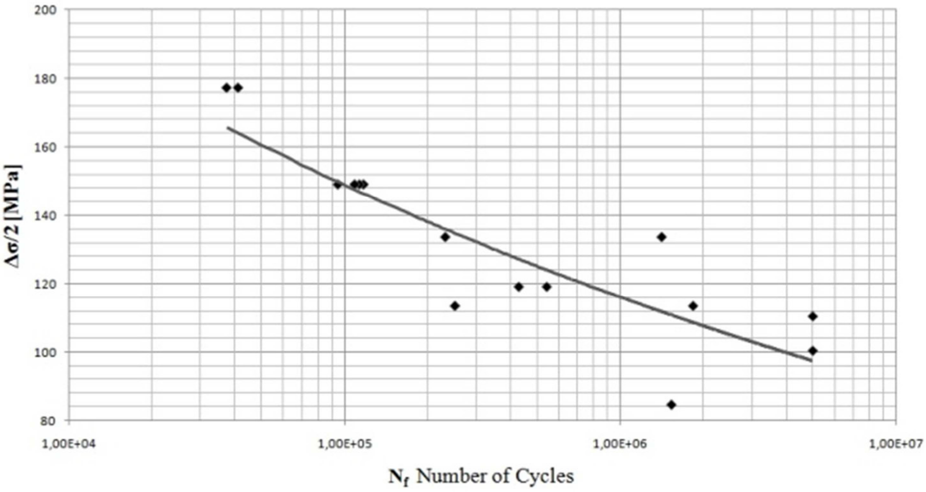

Fig. 3. Wöhler curve for weld metal (R = -1)

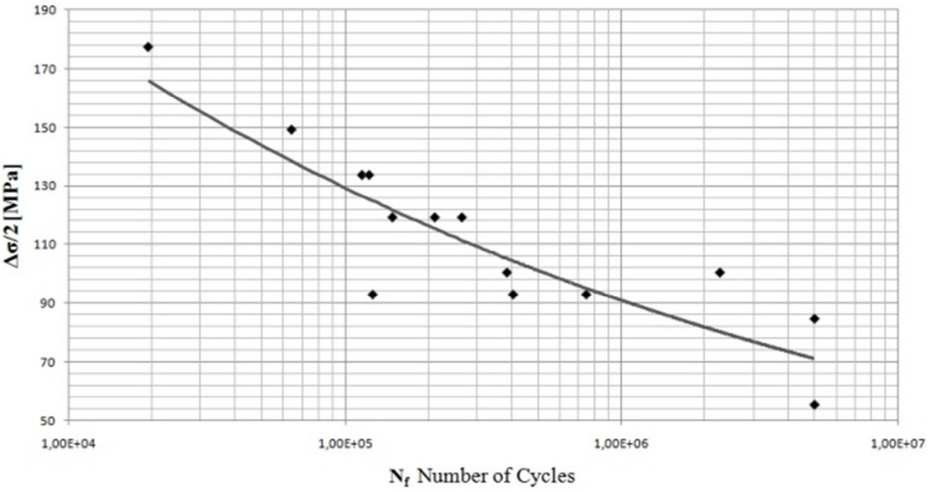

Fig. 4. Wöhler curve for weld metal (R = 0)

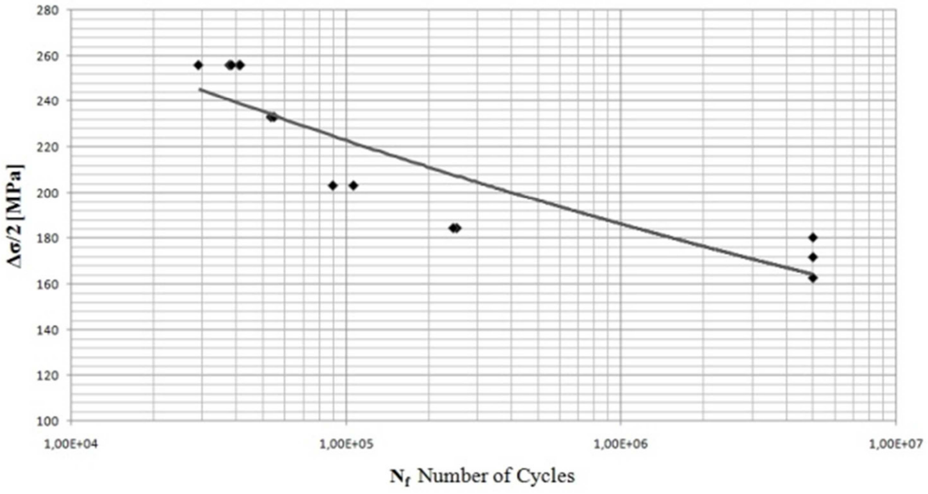

Fig. 5. Wöhler curve for HAZ (R = -1)

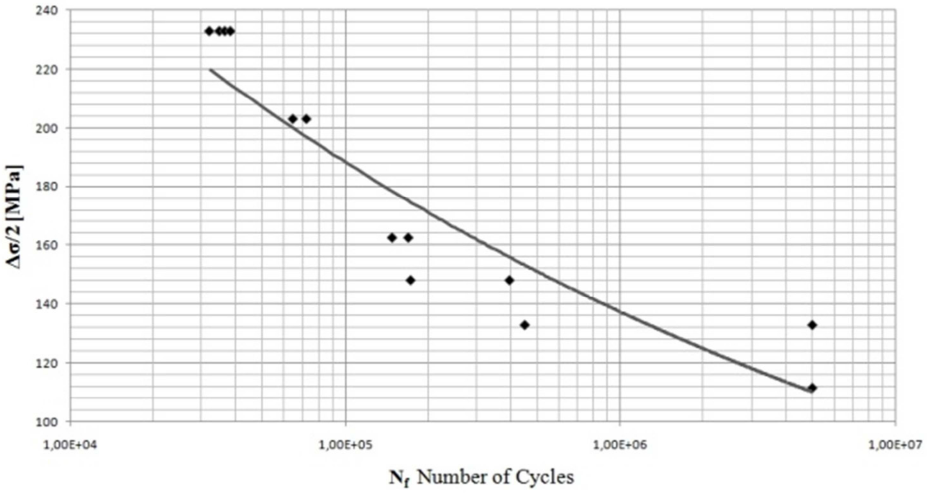

Fig. 6. Wöhler curve for HAZ (R = 0)

5. Discussions and summary

Figures presented in previous section (Fig. 1-6) shows that results regarding the base metal are relatively more consistent than calculations regarding weld metal and HAZ, evident by the less scattered results in comparison. The amounts of scatter in results are especially prominent in specimens with HAZ. This can be attributed to the changes in material state due to high temperature. It should also be noted that the specimens with highest stress amplitudes at notch root are base metal. This can be interpreted as base metal having the highest fatigue strength.

All the presented calculations and discussions points out that Neuber's rule can still be used to make fast estimations regarding fatigue behaviour of magnesium welded joints. This is a novel approach regarding the fatigue behaviour of this material and this research can be extended by using more advanced energy methods for magnesium welded joints. By re-evaluating and extending the usage of energy methods, quick but relatively reliable energy methods can be adopted to evaluate fatigue of structural components. This can benefit design against fatigue in the future, providing more tools for engineers.

It should not be forgotten that Neuber’s method is simply the basis of energy methods. By developing new energy methods and improving existing methods, fatigue models that consider material, weld geometry and weld toe, better and more reliable designs against fatigue can be made. Fast estimations using such methods saves both time and resources by minimizing the need for expensive and time consuming fatigue tests.

Additional information

Selected issues related to this paper are planned to be presented at the 22nd Winter International Scientific Conference on Achievements in Mechanical and Materials Engineering Winter-AMME’2015 in the framework of the Bidisciplinary Occasional Scientific Session BOSS'2015 celebrating the 10th anniversary of the foundation of the Association of Computational Materials Science and Surface Engineering and the World Academy of Materials and Manufacturing Engineering and of the foundation of the Worldwide Journal of Achievements in Materials and Manufacturing Engineering.

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