Developing a full range S–N curve using mathematical model and estimating cumulative fatigue damage of cast iron alloys: a review

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***Abstract*: Recent studies have proved that there is no fatigue limit for metallic materials. The stress life curve continuously drops even after 10^7 cycles. However, existing design codes assume that there is a fatigue limit. Therefore, it is important to use appropriate safety factors if existing codes are used for life evaluations. This paper consist of developing the full range S-N curve from low cycle region to high cycle region upto giga cycle fatigue region of cast iron alloys in ANSYS 16.0 work bench software. Also using monotonic test method to construct a full range S–N curve by employing monotonic test based empirical formulae and Palmgren function (a Wholer field mathematical function). Finally the paper presents the comparison of analytical result with the result obtained from empirical formula developed using mathematical model. At last estimating the cumulative fatigue damage using Mesmacque's sequential law based damage summation model.**

***Keywords*: Full range S-N curve, Giga cycle fatigue, Cast iron alloys, Monotonic test, Wholer field mathematical function, ANSYS**

I. INTRODUCTION

Fatigue failure is a common phenomenon in structures that are subjected to cyclic loading therefore designing against fatigue is important. Fatigue damage of structures is determined by using stress – life (S–N) curves in high cycle fatigue (HCF) and gigacycle fatigue (GCF) regions, while strain – life (e–N) curves are used in low cycle fatigue (LCF) region. Laboratory fatigue testing based S–N curves developed using material samples from structures concerned (structure and material specific S–N curves) produce realistic fatigue damage predictions for those structures. However, fatigue testing is costly, time consuming and requires sophisticated equipment or much time if conventional equipment is used especially in GCF region. Therefore, monotonic test (tensile and hardness tests) based empirical formulae such as the Basquin and Manson–Coffin equation for LCF and HCF regions and Murakami formulae for GCF region are widely used.

Where experimental fatigue data is available, regression analysis based functions such as Strohmeyer function, Palmgren function and recently developed Kohout and Vechet function are useful for constructing S–N curves. However, there are no empirical formulae which are able to accurately describe the entire (full) range of the S–N curve from the first cycle to gigacycle. Therefore, we use monotonic test method to construct a full range S–N curve by employing monotonic test based empirical formulae and Palmgren function(a Wholer field mathematical function).

Miner's linear damage rule is generally used for estimating the cumulative fatigue damage. However, Mesmacque's sequential law based damage summation model (which is capable of accumulating the effect of the loading sequence) is one of the methods employed for predicting the cumulative damage more efficiently than Miner's rule. Sequential law requires a full range S–N curve as the accumulation of the damage is not linear and represented by increasing stresses. Having a full range S–N curve in hand, this paper then compares the fatigue damage estimated using Miner's rule and sequential law, to highlight the differences.

II. LITERATURE REVIEW

[1] Alan Vasko , Milan Vasko
The paper deals with the comparison of fatigue tests of nodular cast iron at high and low frequency cyclic loading. Fatigue tests were realized at high and low frequency sinusoidal cyclic push-pull loading (stress ratio R = –1) at ambient temperature (T = 20 □ 5 °C). High frequency fatigue tests were carried out with using the ultrasonic fatigue testing device KAUP-ZU (frequency f □ 20 kHz); low frequency fatigue tests were carried out with using the fatigue experimental machine Zwick/Roell Amsler 150HFP 5100 (frequency f □ 120 Hz).

[2] S. Schoenborn , H. Kaufmann , C.M. Sonsino , R. Heim
This paper describes that the cumulative damage calculation method generally applied in the automotive sector is the Palmgren Miner Hypothesis with its modification according to Haibach. In several design codes the theoretical Palmgren Miner damage sum D_{th} = 1.0 still recommended as the allowable damage sum D_{al} despite the fact that it renders unsafe calculated fatigue lives.

Results obtained with modern high strength cast iron alloys such as EN-GJS-500-7 , SiboDur 700-10 and MADI (Machinable Austempered Ductile Iron) under a standard Gaussian spectrum for chassis applications and also under a fuller injection pump spectrum suggest the allowable damage sum D_{al} = 0.3 for fatigue life estimations.

[3] M. Jimenez , J. Martinez , U. Figueroa , L. Altamirano

In this paper durability assessment is performed to establish the damage applied by loads and the number of load cycles versus S-N curves. This information is evaluated using a fatigue damage hypothesis. A new relationship is proposed to estimate the S-N curve of nodular cast iron, based on its ultimate strength, using a case study of a steering knuckle component under bending load. Finite element simulation was performed to obtain the maximum stresses in the component using Patran V2012.2 and Nastran V2008 software. Correction factors accounted for surface finish, type of load and level of reliability.

Actual and proposed predictions were evaluated using experimental results. The main aim of this work was to design a fatigue test, with a limited amount of information, through finite element simulation and tensile strength. The main advantage of this relationship over the other methods for estimating an S-N curve, is to improve life prediction at the boundary of low and high cycle fatigue with a simple relationship and without a series of tests to identify the S-N curve, thus simplifying durability assessment with a limited amount of information. The proposed relationship improved the life prediction by an average of 10% in the case study.

[4] A. Laksimi, X. L. Gong & M. L. Benzeggagh

In this paper the object of the study is to investigate the damage and failure mechanisms in a glass-fiber/epoxy composite under monotonic tensile loading. The testing was carried out on unidirectional specimens with and without a circular hole. The damage initiation and failure mechanisms were studied by means of scanning electron microscopy and acoustic emission monitoring. In addition, for specimens with a circular hole, a novel strain-gage instrumentation method is suggested. These different techniques permitted the determination of the damage parameters e, v, D, F, which characterize qualitatively and quantitatively the initiation and evolution of damage. It was found that the amplitude distribution of acoustic emissions is a very efficient tool for identifying damage mechanism such as micro cracking in the resin, fracture and friction of the interface between fiber and matrix, and fiber pull-out.

[5] C. M. Sonsino

Conventional design codes base their recommendations still on the common prejudice that an "endurance limit" exists. However, several investigations prove clearly that in the high-cycle regime a decrease of fatigue strength with increased number of cycles still occurs, even if corrosion or temperature effects are excluded. Therefore, the fatigue design of components submitted to loadings below the knee point of the S-N curve must consider this fact in order to avoid failures. With regard to the course of the S-N curve in the very high cycle area, material and manufacturing dependent recommendations are given.

III. CONCLUSION

From the above literature survey we have found that the assumption taken for designing against fatigue that endurance limit exist for every material is not exact. In several research it has been proved that there is the decrease of fatigue strength with the increased number of cycles in high cycle region and goes on decreasing upto giga cycle region. As the fatigue analysis is time taking and costly and it becomes very difficult as the number of cycle exceeds to giga cycle fatigue region. So I have decided to develop the full range S-N curve for cast iron alloys (specimen) using monotonic test based mathematical model (Wholer Field Mathematical model) and comparing the obtained result with the results obtained from ANSYS and plotting the both results (Mathematical and Analytical) on same graph for checking the accuracy of mathematical model.

IV. REFERENCES

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