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Prediction of the Fatigue Life of the Traction Arm on the New Holland TT75 Tractor in Service in Chad

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Abstract

This study focuses on the prediction of the fatigue life of the traction arm on the New Holland TT75 tractor, which is used under difficult agricultural conditions in Chad. Using finite element simulations on ABAQUS/CAE 2017 and of analysis of the S-N curve for S235JR steel, we estimated the fatigue life under loads cyclic in traction. The equivalent stresses are calculated using Goodman's equation and then compared to the experimental data extracted by PlotDigitizer. The linear Miner, nonlinear Tikri and Lemaitre-Chaboche damage cumul models are applied without overloads to evaluate fatigue strength and generate Gassner curves. The results highlight the sensitivity of the current arms and underscore the value of geometric optimizations.

Keywords

Fatigue, ABAQUS, New Holland TT75, Traction Arm, Goodman, Miner, Tikri, Lemaitre-Chaboche and Life

1. Introduction

The study of the fatigue life prediction for the traction arms of the New Holland TT75 tractor concentrates on the finite life domain. She uses simulations in ABAQUS/CAE 2017 to determine the maximum stresses experienced by the S235JR steel traction arms under different applied pressure [1]. To estimate the experimental life, the equivalent stresses are calculated from the maximum stresses using Goodman's equation to correct for the effect of the average stress [2]-[4], and then compared to the values on the S-N curve for S235JR steel. Equalization can be used to estimate the number of cycles for fatigue initiation. The S-N curve data were extracted using the PlotDigitizer 2.6.8 software [5] [6].

The combination of numerical simulations and experimental data offers a precise estimate. The structured approach evaluates resistance and fatigue life without overloads, using the Palmgren-Miner law, the Tikri model, and the Lemaitre-Chaboche model. For purely repetitive traction with constant amplitude, the cumulative damage model reduces to n/N, but remains useful for quantifying damage and keeping a general calculation framework.

These methods generate Gassner curves and Relative Prediction Errors (RPE) presented as histograms.

No uncertainty analysis, validation dataset, statistical comparison, or p-values are reported; the stated "experimental" lives are digitized from a published S-N curve rather than independent tests.

2. Literature Review

The fatigue of agricultural mechanical components subjected to variable cyclic loads is a major challenge reliability [1]. The Palmgren-Miner law [7] [8], a linear cumulative damage law, remains the most used, although it has limitations when applied to complex loads [9]. Nonlinear models, similar to those proposed by Tikri [10] or Lemaitre and Chaboche [11], improve accuracy by incorporating load interactions and sequence effects [12] [13].

The S235JR steel, generally used in structural applications, presents a well-documented S-N (Wöhler) curve, divided into oligocyclic, finite-life, and endurance zones [5] [6] [14]. Previous studies on the TT75 traction arms have shown stress concentrations at the central hole, motivating geometric optimizations [1]. This work demonstrates the importance of a refined analysis under actual operating conditions in Chad.

The Goodman equation corrects for the effects of average stress in repeated loading [2]-[4] [15].

3. Materials and Methods

The geometric model and load orientation considered here are identical to those of the actual arm (BA) of the New Holland TT75 tractor described by Djondang *et al*. [1].

Material: S235JR steel (E = 200 GPa, $\nu = 0.3$) [6] [14].

Modeling: Finite element simulations on ABAQUS/CAE 2017 with an adapted mesh (C3D8R elements). Approximate global mesh size equal to 0.2 was chosen for the structure.

The applied pressures, ranging from 90 to 125 MPa, were selected to generate equivalent stresses in the fatigue limit region, in accordance with the limited range of our study. Load ratio is R = 0.

3.1. Cycle of Repeated Stress in Traction

When considering only the effects of repeated periodic traction stresses experienced by the traction arms, the stress variations oscillate between the maximum value ($\sigma_{\max}$) and a minimum value of zero ($\sigma_{\min} = 0$); see **Figure 1**.

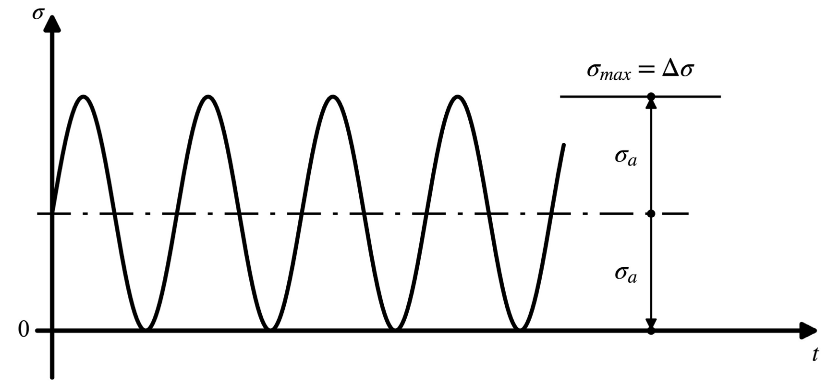

Figure 1. Repeated traction stress [16] [17].

$\sigma_{\max}$ (or $S_{11\max}$) the maximum stress (in MPa);

Calculation of equivalent stresses: Goodman's standard equation.

$$\sigma_0 = \frac{\sigma_a}{\left(1 - \frac{\sigma_m}{R_m}\right)}$$

R_m: the maximum traction stress indicated by the SN curve for S235JR steel;

σ_m: the mean stress (in MPa);

σ_a: the stress amplitude (in MPa).

3.2. Wöhler S-N Curve for S235JR Steel

Extraction of S-N data: PlotDigitizer 2.6.8 on the Wöhler curve of S235JR steel (**Figure 2**).

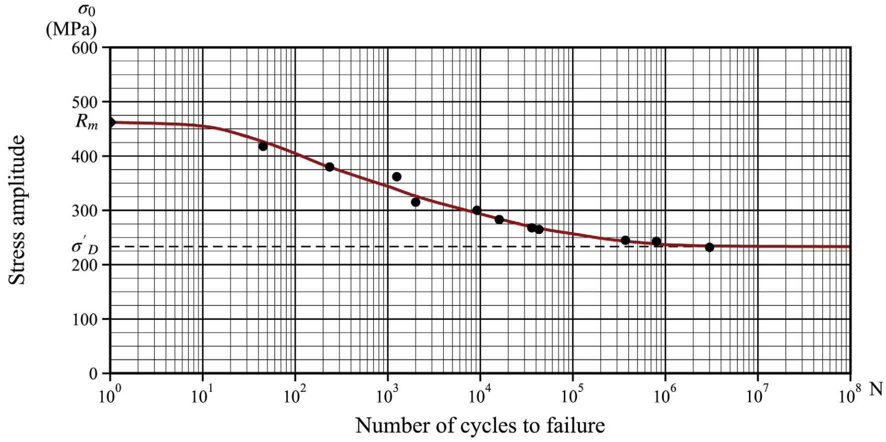

Figure 2. Wöhler curve of S235JR steel [5].

The digitized S-N curve provides reference data rather than experimental validation of the TT75 traction arm; reserve "experimental" for fatigue tests performed on the relevant material or component.

3.3. Life Duration Prediction

3.3.1. Miner's Law (Linear)

Linear equation on a log-log scale for the prediction of life duration from the Miner's law.

$$N_r = 10 \cdot \left(\frac{\sigma_0}{0.9R_m} \right)^{\frac{\log 5.10^6 - 1}{\log \frac{\sigma D'}{0.9R_m}}}$$

N_r: the number of life cycles necessary for the initiation of a crack;

σ_D: limits of endurance indicated by the S-N curve for S235JR steel.

3.3.2. Tikri Model (Nonlinear)

$$N_{rj} = \frac{1}{aM_0^{-0.5\beta}(1+\beta)} \cdot \left(\frac{\sigma_{\max}}{\sqrt{1 - \frac{\sigma_{\max}}{2A.R_m}}} \right)^{-\beta}$$

N_{rj}: estimated life cycle at crack initiation;

a, β, A and M_0 are the constants of the materials.

3.3.3. Lemaitre-Chaboche Model (Nonlinear)

$$N_{fj} = \frac{1}{aM_0^{-\beta}(1+\beta)K_j} \cdot \left(\frac{1 - b\sigma_{mj}}{\sigma_{aj}} \right)^{\beta}$$

With:

$$\frac{1-\alpha_j}{a} = K_j = \frac{\sigma_{\max} - \sigma_c}{R_m - \sigma_D}$$

N_{fj}: is the number of cycles necessary to initiate a crack in the material under a constant-amplitude loading defined by the peak stress (σ_{aj}) and the mean stress (σ_{mj}).

σ_c: stress at the conventional endurance limit at 2.10^6 cycles.

3.4. Safety Criteria for Damage

The criteria for identifying safe zones are based on the Error Relative of Prediction (ERP).

$$ERP(\%) = \frac{N_{\exp} - N_{loi}}{N_{\exp}} \times 100$$

N_{exp}: number of life cycles obtained by extraction from the experimental curve;

N_{loi}: number of life cycles calculated by law or by the model.

4. Results and Discussion

4.1. Calculation of Equivalent Stresses

The following table presents the maximum stresses ($S_{11.\max}$) and equivalent stresses

(σ_0) for the traction arm, obtained by simulation and the Goodman correction (**Table 1**).

Table 1. Equivalent stresses in repeated traction under different applied pressures.

Pressure applied in MPa	Maximum stress	Equivalent stress
	$S_{11.max}$ (MPa)	σ_0 (MPa)
90	314.7	239.1574426
95	332.2	259.9727799
100	349.7	282.0655795
105	367.2	305.5571635
110	384.7	330.5847188
115	402.2	357.3039784
120	419.7	385.8924645
125	437.1	416.3719197

4.2. Data Extracted from the S-N Curve

Table 2 groups the equivalent stress values extracted from the experimental Wöhler S-N curve, corresponding to those calculated from numerical simulations of the traction arm under the applied pressure, along with the associated experimental cycle numbers.

This evaluation is important for guaranteeing the reliability and safety of mechanical agricultural systems [1].

Table 2. Extraction of S-N data: PlotDigitizer 2.6.8 on the Wöhler curve of S235JR steel.

Pressure applied in MPa	Equivalent Stress in MPa	Life cycle extracted (N)
90	239	132,756
95	260	35,229
100	282	13,174
105	306	4575
110	331	1475
115	357	614
120	386	222
125	416	74

4.3. The Prediction of the Service Life

The prediction of the service life of each arm is based on Miner's law as well as the Tikri and Chaboche models. These approaches make it possible to construct Gassner curves (**Figure 3**) and calculate the relative prediction errors (ERP), presented as histograms (**Figure 4**), in order to evaluate fatigue resistance.

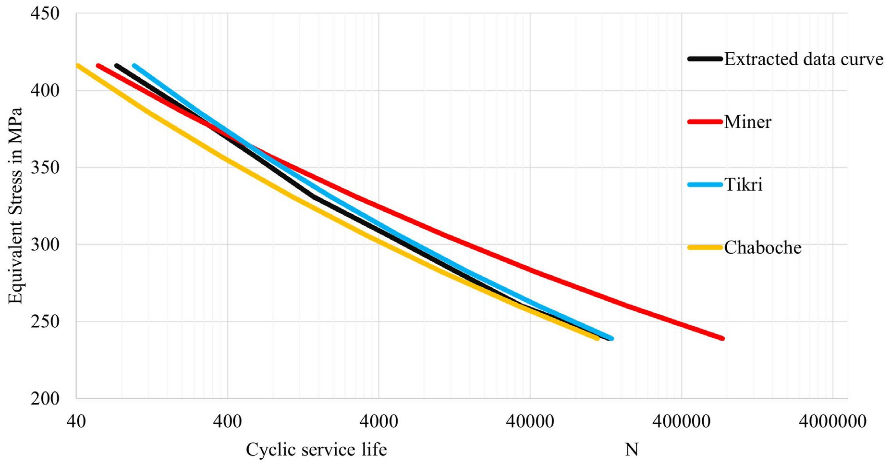

Figure 3. Gassner's S-N curves.

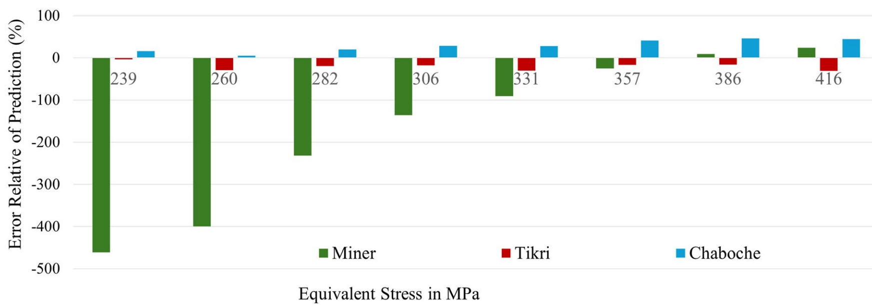

Figure 4. Histogram of ERPs (%) as a function of the applied pressure of the current arm.

The analysis of the performance of the fatigue models proposed by Miner [8], Tikri [10], and Chaboche [11] under different equivalent stress ranges highlights the importance of selecting the appropriate model based on the context (safety and optimization).

- Miner's law: It is conservative at high stress levels but non-conservative at lower stress levels, as frequently reported in the literature on linear cumulative damage [9].
- Tikri model: Less conservative, useful for optimization but requiring experimental validation.
- Chaboche model: More conservative, adapted to critical applications where a safety margin is essential [11].

The model choice must be based on the application's specific safety, performance and cost requirements, in the context of agriculture in Chad. Geometric optimizations of the traction arms are recommended to improve fatigue life [1]. The analysis reveals that Miner's law is conservative at high stress levels but becomes non-conservative at low stress levels. The Tikri model is generally less conservative, while the Chaboche model provides a more cautious and safer approach over the full range of stresses studied. The choice of model depends on the project's priorities: security (Chaboche), economic optimization (Tikri), or easy application (Miner).

5. Conclusions

This study estimated the fatigue life of the drawbars on the New Holland TT75 tractor under Chadian agricultural conditions by combining finite element simulations, the Goodman correction and different damage cumulative models.

Among the models evaluated, the Lemaitre-Chaboche model proves to be particularly well-suited for high-risk applications because of his conservative character. The Tikri model, for its part, offers a good balance between accuracy and optimization. Miner's law, although simple to use, presents significant limitations at low stress levels. Supplementary experimental tests on a fatigue test bench are recommended to validate these numerical predictions. In the term, this approach should contribute to improving the reliability of agricultural equipment in Chad and in the Sahelian regions, subjected to harsh operating conditions.

Author Contributions

Conceptualization, Djondang Sindang; methodology, Djondang Sindang, Tchoudang Sehoret and Kinet Ouinra; software, Djondang Sindang; validation, Djondang Sindang, Tchoudang Sehoret and Kinet Ouinra; formal analysis, Djondang Sindang; investigation, Djondang Sindang; resources, Djondang Sindang; data curation, Djondang Sindang; writing—original draft preparation, Djondang Sindang; writing—review and editing, Djondang Sindang, Tchoudang Sehoret and Kinet Ouinra; visualization, Djondang Sindang; supervision, Tikri Bianzeubé; project administration, Djondang Sindang; funding acquisition, Djondang Sindang, Tchoudang Sehoret and Kinet Ouinra. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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