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Incorporating Material Fatigue Parameter Determine in The Rolling & Sliding Contact Fatigue Analysis of Gears

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Abstract

As the material's intricate stresses and strains are always shifting during phases of loading, determining the predicted equipment working under rolling-sliding contact loads and their fatigue lives (wheels, bearings, and gears) is particularly difficult. Another difficulty is not knowing the precise characteristics of the material used to make the components, which is particularly noticeable. when it comes to heat-treated components, where the material characteristics' values can differ greatly among the equipment. Depending on the findings of fatigue measuring involute spur gears constructed of 42CrMo4 steel that has undergone various heat treatments. According to recently published findings, the previously suggested multiaxial fatigue life measurements methodology as reported by the Fatemi-Socie critical plane-based crack start criterion was used to conduct fatigue life studies of the flanks of gear teeth. Due to the lack of real cyclic and fatigue material factors, an estimating method particularly designed for 42CrMo4 steel was used, utilizing the materials' monotonic properties as provided in previous studies. Very good agreement is found between investigational and computed fatigue lives, or load carrying capacities, indicating that advanced material parameter estimation is applicable to studies of genuine elements' fatigue and inability under rolling sliding contact loads.

Keywords: Fatigue, gear teeth, Characteristics, Brinell Hardness, yield strength

INTRODUCTION

Through the exception of the simplest ones, deciding the work of determining the load-bearing capability or mechanical tenacity parts, constituent, and constructions is sophisticated and involves the evaluation of several parameters, intricate designs, as well as complicated loads. For heavily loaded units subjected loading, just as gears, rollers, or bearings, this is particularly relevant since the interaction of these elements causes complicated multiaxial states of stress and strain in the material. [1]. Using extremely simplified terms like shear loading/stress and shear strength, various instances are introduced along with comparable types of damage that occur at the flanks of the gear teeth. A portion of the problem's complexity is already apparent by this problem's reduced depiction [2].

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Figure 1. Fatigue failure of gear teeth.

The literature has provided a plethora of methods and procedures for calculating the load-bearing ability and permanence—that is, the fatigue lifetimes of gears and differ constituents using in rolling-sliding contact loading regimes—for these components. They span from early works based on actual data and simpler investigation models by Pederson and Rice (1961) and Sandberg (1981) to more contemporary ones like Glodež et al. (1996) that include Von Mises stress as a key parameter. Zwirlein and Wieland (1983) employed a stress-based approach, while Raml et al. (2003) and Raml and Flašker (2007) employed strain-based models. Fatemi and Socie's (1988) critical plane-based fatigue crack initiation criterion is used in more modern modeling and fatigue life estimation techniques. The majority of current methods use multi-scale, i.e., Mlikota et al. (2021) conducted micro-structurally-based fatigue crack initiation modeling, and Mlikota and Schmauder (2020) presented critical resolved shear stress. The inability to precisely determine the properties of the material used to create both monotonically - cyclically loaded components is a major challenge that should be minimised in the computation and analysis process, regardless of the specific problem or approach chosen. This is particularly evident when dealing with heat-treated components, as the material properties can vary greatly within the component. In addition to being exceedingly expensive in terms of both time and money, experimentally determined material characteristics and attributes or comprehensive material reaction are typically not available for testing. As a result, employing current facts and details from references or other data sources is frequently used. Still another option, though, is to use a variety of estimating techniques. One instance of this is research on the large-diameter induction-based slewing bearings of onshore wind turbines. Friederici et al. (2021) conducted a study on hardened and tempered steel 42CrMo4, involving a significant amount of experimental work to extract material specimens, test them to define the material, and make estimations. techniques can have been used in addition to the straightforward non-destructive testing techniques that were carried out. Using measured values of Vickers hardness, Vukelic et al. (2021) assess the pressure vessel steel's ultimate strength in a breakdown analysis of a pressure vessel that has burst. This is a well-known possibility. The estimation of strain-life can be carried out in a similar way for possible future research. In order to maintain static and fatigue assessments on coil springs. additionally calculate ultimate strength using Vickers hardness, and obtain the necessary fatigue values from the accessible published reference. The parameters required for strain-life fatigue study are taken from the program for numerical analysis by Papadopoulou et al. (2019). Here, Given the availability of roll steel pin failure samples and the potential for hardness assessment (perhaps including static tensile testing), it may have been possible to estimate them from monotonic properties.

Model For Evaluating Fatigue Life Along with Methods for Evaluating Material Characteristics

The current study's objective is to assess the usefulness of estimating techniques for the investigation of the durability and load-carrying capability of gear tooth flanks. In order to do Fatemi-Socie (FS) and a mathematical model of rolling-sliding line contact were integrated. The critical plane crack initiation criterion is applied, which was first put forth by Basan and Marohnić (2019). In addition to calculating the number of load reversals required for fatigue failure and fracture initiation, the model allows for the calculation of the most probable places for crack initiation and, depending on the orientation of critical planes, the type of damage that will likely result from the cracks. The equivalent deformation (von Mises) criterion is used in place of the shear fatigue parameters used in the original form of the FS criteria. The majority of suggested estimation methods assess the axial fatigue strain-life parameters, which can be expressed in the following form. Numerous estimating techniques, such as those proposed by Manson (1965), Bäumel and Seeger (1990), and Roessle and Fatemi (2000), have been proposed in the literature to enable the calculation of strain-life and cyclic stress-strain fatigue characteristics using monotonic and other kinds of materials. New ones are being produced aggressively and continuously.

$$\frac{\Delta\left(\frac{\gamma max}{2}\right)}{2}\left(1+k\frac{\sigma_n^{max}}{R_e}\right)=\frac{\sigma_f'}{G\sqrt{3}}(2Nf)b+\in_f'\sqrt{3}(2Nf)c \qquad \text{Eq-1}$$

Particularly those that rely on artificial neural networks and alternate machine-learning-based strategy and archetype, as these allow for the modeling of far more intricate relationships between monotonic and cyclic/fatigue parameters as well as the involvement of more input fluctuation, or identical attributes, than is feasible with traditional techniques. For real-world applications, still approaches with fewer input parameters are usually more advantageous and objectives since the number of monotonic features and other relevant data that are used as the basis for estimation are not always readily available. neither readily accessible nor easily obtained. This work used the estimation method for Basquin-Coffin-Manson guidelines of low-alloy steel 42CrMo4 that was originally proposed in Basan et al. (2010) and associated equations (2 to 5), as well as ivvolved in Basan et al. (2015), Basan et al. (2019). The primary input in estimation expressions is Brinell hardness. The fact that different fatigue parameters are not addressed separately is a unique and variable feature.

$$\frac{\sigma_f'}{E} = 10^{-4-(\frac{HB^2}{12981}+\frac{HB}{1259}+5919)b} \qquad \text{Eq-2}$$

$$b = \left(\frac{HB^2}{26781} - \frac{HB}{31056} - 6{,}3\right)-^1 \qquad \text{Eq-3}$$

$$\epsilon_f' = 10^{-4-(\frac{HB^2}{132520}} + \frac{HB}{19517} + 6403)c \qquad \text{Eq-4}$$

$$C = \frac{HB^2}{328103} + \frac{HB}{356} - 1955)-^1 \qquad \text{Eq-5}$$

ANALYSIS AND RESULTS

The findings of a comprehensive experimental investigation of multiple feasibility of the fatigue factor estimate procedures for determining the fatigue lifetimes of gear teeth flanks subjected to recurrent rolling-sliding contact loads was evaluated using gear pairs by Niemann and Bötsch (1966). The number consecutive gear pairs in the study for which the primary gearing parameters, which were tested on various combinations of quenched and tempered low-alloy steel 42CrMo4, are listed in Table 1. Table 2 gives details on the material property of each gear pair, including operating conditions and hardness following heat treatment. The original reference contains more information.

Table 1. Specification of inspected gear pairs

S. N	Specification	Pinion	Gear
1	"normal module", in mm	5	
2	"normal pressure angle", αn	20°	
3	"number of teeth" Z_1 & Z_2	25	40
4	profile shift coefficients, X_1 & X_2	0	
5	facewidth, b_1, b_2	20	
6	transverse contact ratio, εα	1:65	
7	"center distance" a in mm	91.5	

Table 2. Condition, hardness, loading, and predicted coefficient of friction of the gears in the grid.

S. No	Specification	Gear Pair (GP) 1	(GP) 2	(GP) 3	(GP) 4
1	Material and condition	42CrMo4, Q&T	Same	Same	Same
2	Yield Stress Re	560	635	890	985
3	Brinell Hardness HBTotal Normal Force FbtCoefficient of Friction	2202754	25533400.04	3204650	3406010

Using the formula, the Vickers hardness values from the research were converted to Brinell hardness.

$$HB = -2407{,}5 + \sqrt{5752500} + 5000HV \qquad \text{Eq-6}$$

Table 3. Values of Basquin-Coffin-Manson fatigue specifications obtained from Brinell hardness.

S. No	Parameter	Pair-1	Pair-2	Pair-3	Pair-4
1	material and condition	42CrMo4, Q&T	Same	Same	Same
2	Brinell Hardness HB	215	240	310	325
3	fatigue strength coefficient	0.0049	0.0053	0.0067	0.0068
4	fatigue strength exponent	-0.08	-0.084	-0.0789	-0.076
5	fatigue ductility coefficient	0.9600	1.031	1.0156	0.970
6	fatigue ductility exponent	-0.669	-0.686	-0.731	-0.732

The fatigue lives obtained by the use of estimated fatigue specifications and those obtained even so experimentation was differentiated through proportions of the fatigue lives of independent gear pairs and the largest fatigue life of a specific gear pair (gear pair 3 in the observational investigation and gear pair 4 in the analysis). The image in Figure 2 illustrates how the increased hardness of the gear teeth the investigational fatigue lives of the investigated gear pairs grow with the material of the flanks. This change is closely followed by the computed fatigue lifetimes, with a modest variation only noticeable between the materials (310 HB and 325 HB) with slightly different hardness values.

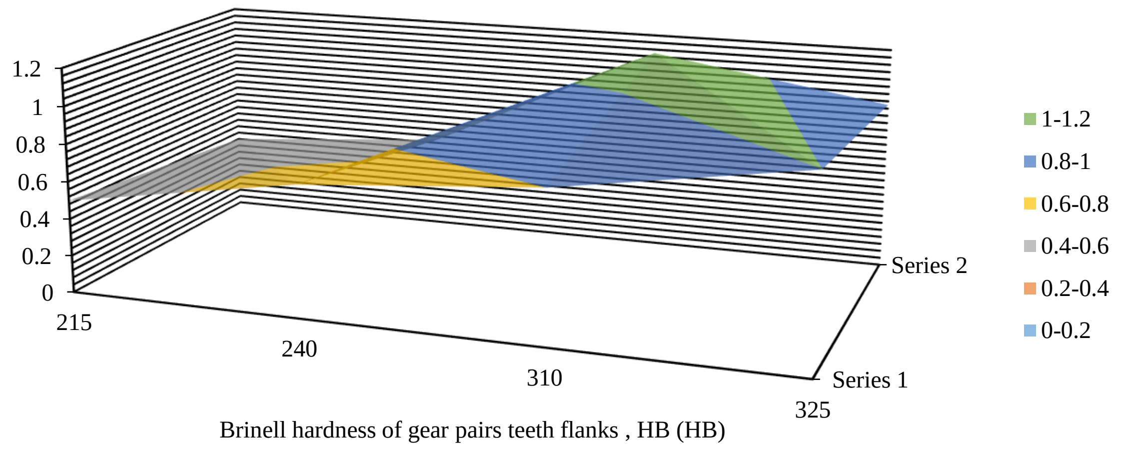

Figure 2. Comparative analysis of the computed and empirical fatigue lifetimes of the teeth flanks of examined gear sets.

CONCLUSIONS

The necessary fatigue data has been estimated using expressions that were created on material datasets that were entirely unrelated to the material specifics used in the investigational analysis of the gear pairs under consideration. seemingly inferred from the discovery of this present work that there is a reasonable degree of agreement between the calculated and experimental durability of the examined gear pairs, given that the materials of the gears were relatively similar and that each individual gear pair was loaded differently. The multiaxial fatigue life calculation model based on the Fatemi-Socie (FS) critical plane crack initiation criteria has been validated by previous analyses and studies. Therefore, it seems that the selected estimation method and associated expressions can be effectively utilized for the estimation of sophisticated material parameters in fatigue and failure analyses of actual elements that have undergone rolling-sliding contact transferring. Together with further studies and validations, computational modelling and examinations of edge-hardened elements where the material and related properties and features modify with their proximity to their exterior will be carried out.

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