Springer

KSME

Journal of Mechanical Science and Technology 30 (3) (2016) 1129~1137
www.springerlink.com/content/1738-494x(Print)/1976-3824(Online)
DOI 10.1007/s12206-016-0217-3

Determining the Walker exponent and developing a modified Smith-Watson-Topper parameter model †

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(Manuscript Received April 28, 2015; Revised October 8, 2015; Accepted November 4, 2015)

Abstract

Mean stress effects significantly influence the fatigue life of components. In general, tensile mean stresses are known to reduce the fatigue life of components, whereas compressive mean stresses are known to increase it. To date, various methods that account for mean stress effects have been studied. In this research, considering the high accuracy of mean stress correction and the difficulty in obtaining the material parameter of the Walker method, a practical method is proposed to describe the material parameter of this method. The test data of various materials are then used to verify the proposed practical method. Furthermore, by applying the Walker material parameter and the Smith-Watson-Topper (SWT) parameter, a modified strain-life model is developed to consider sensitivity to mean stress of materials. In addition, three sets of experimental fatigue data from super alloy GH4133, aluminum alloy 7075-T651, and carbon steel are used to estimate the accuracy of the proposed model. A comparison is also made between the SWT parameter method and the proposed strain-life model. The proposed strain-life model provides more accurate life prediction results than the SWT parameter method.

Keywords: Mean stress effects; Walker method; Mean stress correction; Strain life; SWT parameter

1. Introduction

Structural components in engineering are subjected to time-varying loads in the presence of mean stress. In engineering applications, symmetric cyclic loads, wherein the mean stress is zero, rarely occurs. Numerous investigations [1-4] have shown that mean stress effects significantly influence the fatigue life of structural components. To date, various approaches have been proposed to study the effects of mean stress on fatigue life. Under given cyclic loads, tensile mean stresses are known to reduce the fatigue life of structures, whereas compressive mean stresses are known to increase it [5, 6].

The effects of mean stress depend on the physical properties of a material, which can be included in various manners. Recent methods have been successful in considering mean stress effects on fatigue life. The Goodman [1], Morrow [2], Walker [3], and Smith-Watson-Topper (SWT) [4] methods are the most widely used mean stress correction methods in engineering. However, certain disadvantages exist among these methods. Ref. [7] reported that the result from the modified Goodman method with the ultimate tensile strength was highly conservative. Dowling [8] concluded that the Morrow equation was inaccurate because the fatigue strength coefficient was significantly different from the true fracture strength. The SWT method provides good life prediction results in the long fatigue life region, but is conservative in the low cycle fatigue life region [9]. Ince and Glinke [10] proposed a modified Morrow and SWT mean stress correction model, wherein only the elastic strain amplitude was corrected. The Morrow model was found to provide the least accurate life prediction results, whereas the SWT parameter model could yield acceptable life prediction results, but its prediction trends remained slightly conservative. Ref. [11] presented a modified SWT parameter model under non-proportional loading, wherein a damage parameter that represented the effective strain energy density was introduced. Furthermore, the SWT parameter model can only consider fatigue damage caused by tensile components. The Walker method with an additional adjustable material parameter γ can provide the best mean stress correction for all kinds of materials [12, 13]; however, it also has a disadvantage, that is, its adjustable material parameter γ is difficult to obtain.

The value of the adjustable material parameter γ of the Walker method requires additional efforts and experiments to obtain, which limits the application of this method in engineering. The SWT parameter is an extension of the mean stress correction SWT method, which is introduced in detail in a later section. Although the SWT parameter is the most

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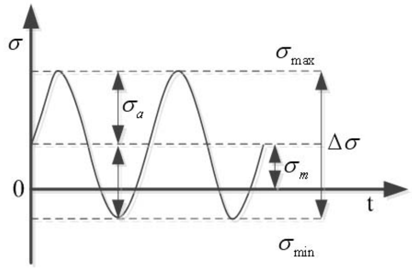

Fig. 1. Constant amplitude cyclic loading.

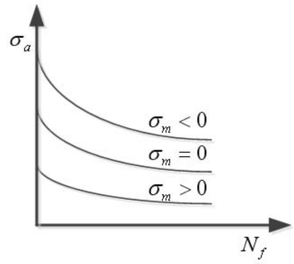

Fig. 2. Illustration of the effects of mean stress.

widely used strain-life method in engineering, it also has a drawback, that is, it does not consider the mean stress sensitivity of materials. The material parameter γ of the Walker method can be used to describe the mean stress sensitivity of different materials [12]. Therefore, we first develop a practical method to estimate the value of the adjustable material parameter γ of the Walker method in this study. Second, after combining the Walker material parameter γ and the SWT parameter, we propose a modified life-strain model in which the concept of mean stress sensitivity is incorporated into mean stress analysis. Third, we use the test data of different materials and three sets of experimental fatigue data to verify the proposed practical method and the modified life-strain model. Finally, we compare the SWT parameter and the modified life-strain model.

2. Effects of mean stress

The physical properties of a material influence the magnitude of mean stress. When correcting mean stress, two specified characteristics must be considered: the mean stress sensitivity and the mean stress relaxation of a material. The effects of mean stress can influence the fatigue strength and lifetime of a material [14]. The cyclic load histories of structural components generally have a non-zero mean stress, which has a load variation ranging from the minimum to the maximum values. Under working condition, stress cycles will be repeated for a considerable number of times. The cyclic loads of structural components can be described by stress amplitude σ_a, mean stress σ_m, stress range $\Delta\sigma$, and stress ratio R [15]. These parameters can be expressed as follows and as illustrated in Fig. 1.

Stress amplitude:

$$\sigma_a = \frac{\sigma_{\max} - \sigma_{\min}}{2} \; ; \tag{1}$$

Mean stress:

$$\sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2} \; ; \tag{2}$$

Stress range:

$$\Delta\sigma = \sigma_{\max} - \sigma_{\min} \; ; \tag{3}$$

Stress ratio:

$$R = \frac{\sigma_{\min}}{\sigma_{\max}} \, . \tag{4}$$

The empirical relationships between mean stress and fatigue life have been studied for a long time. Various mean stress correction methods have been developed to address the effects of mean stress on fatigue life, such as the Goodman, Morrow, Walker, and SWT methods. Tensile mean stress is known to have detrimental effects on fatigue life, whereas compressive mean stress has beneficial effects on fatigue life [16], as shown in Fig. 2. In the present study, N_f indicates the cycles to failure.

A brief review of the Goodman, Morrow, Walker, and SWT mean stress correction methods is provided in this paper. These four widely used mean stress correction models are shown under fluctuating loads as follows:

Goodman method [1]:

$$\frac{\sigma_a}{\sigma_{ar}} + \frac{\sigma_m}{\sigma_u} = 1 \; ; \tag{5}$$

Morrow method [2]:

$$\frac{\sigma_a}{\sigma_{ar}} + \frac{\sigma_m}{\sigma_f} = 1 \; ; \tag{6}$$

Walker method [3]:

$$\sigma_{ar} = \sigma_{\max}^{1-\gamma}\sigma_a^{\gamma} \; ; \tag{7}$$

SWT method [4]:

$$\sigma_{ar} = \sqrt{\sigma_{\max}\sigma_a} \; ; \tag{8}$$

where σ_{ar} is the equivalent alternating stress amplitude at zero mean stress, σ_u is the material ultimate strength, σ_f is the true fracture strength, and γ is an adjustable material parameter.

In Refs. [8, 10, 12], the Goodman mean stress equation was regarded to be the most inaccurate; the Morrow method was reasonably accurate in most cases when true fracture strength was available; the Walker equation with the adjustable material parameter γ provided the best mean stress correction; and the SWT equation was a good choice for aluminum alloys. Furthermore, when γ = 0.5, the Walker equation will be simplified to the SWT equation. That is, the SWT equation is a special case of the Walker equation. Consequently, the SWT method is less accurate than the Walker method. Therefore, the Walker method should be given more attention based on its best mean stress correction.

3. Determining the Walker exponent

As mentioned in the preceding sections, the Walker method provides the best mean stress correction for all kinds of material compared with the other three methods. However, the application of this method in engineering is limited because of the unavailability of its adjustable material parameter γ. To date, obtaining material parameter γ still requires additional effort and experiments, which makes using the Walker method in engineering applications difficult. To extend the application of the Walker method, a practical procedure is proposed to determine its material parameter γ in this section.

In Refs. [3, 12], γ was regarded as a material constant that would indicate the sensitivity of materials to mean stress. When the value of γ is high, the sensitivity of a material to mean stress is low. Brittle ductile materials are more sensitive to mean stress than ductile materials [14]. Furthermore, a relationship exists between the material parameter γ and the ultimate tensile strength σ_u of a material [12]. However, an acceptable method that can fully connect parameter γ with the physical properties of a material remains unavailable. In this section, we determine that yield tensile strength σ_o and ultimate tensile strength σ_u can be used to describe material parameter γ by analyzing the test data of the parameters of the physical properties of materials. An acceptable practical method is then proposed based on this finding.

In Table 1, several test data of the monotonic and fatigue properties (yield strength σ_o, ultimate strength σ_u, true fracture σ_{fB}, area reduction ψ and material parameter γ) of materials are presented [12].

By analyzing the test data provided in Table 1, the following assumptions are made.

(1) The values of test parameter γ vary from 0.4 to 0.8.

(2) In general, for the same kind of materials, when the values of yield strength σ_o, ultimate strength σ_u, and true fracture strength σ_{fB} are large, the value of material parameter γ is small. However, no such conclusion can be drawn for different kinds of materials.

(3) An internal relationship exists among yield strength σ_o, ultimate strength σ_u, and material parameter γ. With the decreasing range of values between yield strength σ_o and ultimate strength σ_u, the γ value is approximately equal to 0.5.

In this study, a mathematical equation is proposed to describe the relationship among material parameter γ, yield strength σ_o, and ultimate strength σ_u based on the aforementioned boundary conditions. This mathematical equation is given as follows:

$$\gamma = 0.5 \pm \frac{\sigma_u - \sigma_o}{\sigma_u + \sigma_o} . \tag{9}$$

Table 1. Monotonic and fatigue properties of materials.

Materials	σ_o (MPa)	σ_u (MPa)	σ_{fB} (MPa)	ψ (%)	Test γ
SAE 1015 St	228	415	726	67.9	0.7352
GSMnNi63 St	312	501	846	26	0.8113
Ck45 St	531	790	1271	60	0.6949
SAE 4130 St, Norm	647	799	1144	15.2	0.6903
CC 450 SS, H1150	678	1015	1360	23.2	0.6253
SAE 4130 St, Hard	1200	1241	1586	8.3	0.5457
CC 450 SS, H900	1354	1405	1750	15.3	0.4758
PH13-8Mo SS, H1000	1358	1413	1758	-	0.5969
300M St	1634	1958	2303	-	0.4157
SAE 1045 St,705HB	1827	2082	2131	2	0.4839
SAE 1045 St, 55HRC	1731	2165	2690	38	0.4286
6061-T6 Al	276	310	420	-	0.6330
Al Mg4.5Mn, Cld Rl	298	363	476	13	0.6681
2014-T6 Al	438	494	581	13.6	0.4803
7075-T6 Al	489	567	729	16.5	0.4150
7075-T6 Al	521	572	736	12.3	0.4774
Ti-6Al-4V	1006	1034	1271	14.5	0.5431

The same kind of materials demonstrates similar physical performances. Therefore, observing the γ values of the same kind of materials can determine whether the γ value is greater than or less than 0.5. Notably, when the values of yield strength and ultimate strength are large, the value of γ is small.

To verify the capability of the proposed practical method, the test data provided in Table 1 are used to assess the accuracy of Eq. (9). The proposed γ values, which are calculated using Eq. (9), are presented in Table 2. Comparison is then made between the calculated material parameter γ and the test material parameter γ, as shown in Fig. 3.

The solid line in Fig. 3 indicates that test γ = proposed γ. When the data points are close to the solid line, the calculations will be accurate. The dashed lines denote the scatter band of ±1.2. According to Fig. 3, the proposed γ values are highly accurate and completely agree with the test γ values. All the calculated results fall within a scatter band range of ±1.2, which indicates that a relationship exists between parameter γ and the physical properties of materials. Yield strength σ_o and ultimate strength σ_u can be successfully used to describe the material parameter γ of the Walker equation. The calculations also show that the method proposed in this study is acceptable.

4. Strain-life equations with mean stress

The strain-based fatigue life method is widely used in

Table 2. Test γ and proposed γ values of different kinds of materials.

Materials	σ_o (MPa)	σ_u (MPa)	Test γ	Proposed γ
SAE 1015 St	228	415	0.7352	0.7908
GSMnNi63 St	312	501	0.8113	0.7325
Ck45 St	531	790	0.6949	0.6961
SAE 4130 St, Norm	647	799	0.6903	0.6051
CC 450 SS,H1150	678	1015	0.6253	0.6991
SAE 4130 St, Hard	1200	1241	0.5457	0.5168
CC 450 SS, H900	1354	1405	0.4758	0.4815
PH13-8Mo SS, H1000	1358	1413	0.5969	0.5198
300M St	1634	1958	0.4157	0.4098
SAE 1045 St,705HB	1827	2082	0.4839	0.4348
SAE 1045 St, 55HRC	1731	2165	0.4286	0.3886
6061-T6 Al	276	310	0.6330	0.5580
Al Mg4.5Mn, Cld Rl	298	363	0.6681	0.5983
2014-T6 Al	438	494	0.4803	0.4400
7075-T6 Al	489	567	0.4150	0.4261
7075-T6 Al	521	572	0.4774	0.4533
Ti-6Al-4V	1006	1034	0.5431	0.5137

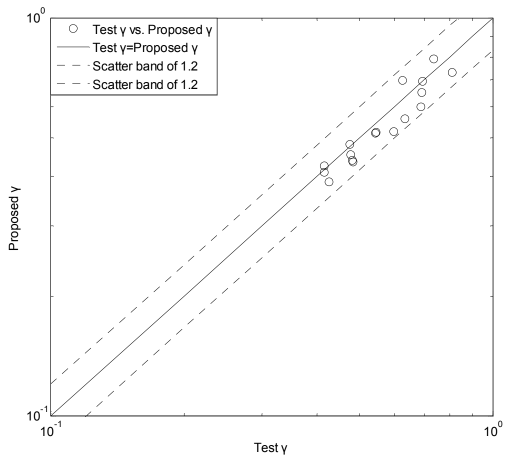

Fig. 3. Comparison between the test γ and the proposed γ values.

engineering nowadays. The stain-life approach represents the relationship between strain amplitude and fatigue life. The relationship between the strain amplitude and fatigue life of components obtained using Basquin's equation is the most commonly accepted. Basquin stated that strain life would follow a power function, which could be expressed with true elastic strain amplitude and fatigue life as follows [17]:

$$\varepsilon_e = \frac{\sigma_a}{E} = \frac{\sigma_f'}{E}\left(2N_f\right)^b , \quad (10)$$

where ε_e is the elastic strain amplitude, σ_f' is the fatigue strength coefficient, E is the elastic modulus, N_f is the fatigue life, and b is the fatigue strength exponent.

Afterward, Manson and Coffin proved that the plastic strain amplitude could be expressed as [18]

$$\varepsilon_p = \varepsilon_f'\left(2N_f\right)^c , \quad (11)$$

where ε_p is the plastic strain amplitude, ε_f' is the fatigue ductility coefficient, and c is the fatigue ductility exponent.

The strain-life method can then be represented in a powerful relationship with the sum of the elastic and plastic amplitudes, which can be expressed as

$$\varepsilon_a = \varepsilon_e + \varepsilon_p = \frac{\sigma_f'}{E}\left(2N_f\right)^b + \varepsilon_f'\left(2N_f\right)^c . \quad (12)$$

However, Eq. (12) has a drawback, that is, it can only be applied to a completely reversed loading case when mean stress is zero. Consequently, this method cannot account for mean stress effects on fatigue life.

With regard to this problem, recent strain-based fatigue life methods have successfully considered mean stress effects, particularly in finite lives. A popular model was proposed by Morrow. In this model, a parameter is introduced into the elastic term in Eq. (12) to consider mean stress effects by combining Eq. (6) with Eq. (12). He [19, 20] stated that mean stress only affected the elastic part of the strain-life equation. This popular model is expressed as

$$\varepsilon_a = \frac{\sigma_f' - \sigma_m}{E}\left(2N_f\right)^b + \varepsilon_f'\left(2N_f\right)^c . \quad (13)$$

However, this model can only provide good life prediction results when the values of the fatigue strength coefficient σ_f' and the true fracture strength σ_{fB} are approximately equal. For other materials, such as aluminum alloys, the life prediction results obtained using this method are unacceptable when a large difference exists between the values of σ_f' and σ_{fB}.

The SWT parameter, which is a more popular strain-life method than the Morrow model, can account for the effects of mean stress [4]. This method is an extension of the SWT model, which combines Eqs. (10) and (12). In Basquin's equation, a relationship exists for completely reversed loading, as follows:

$$\frac{\sigma_a}{E} = \frac{\sigma_{\max}}{E} = \frac{\sigma_f'}{E}\left(2N_f\right)^b . \quad (14)$$

Eq. (14) can be simplified to

$$\sigma_{\max} = \sigma_f'\left(2N_f\right)^b . \quad (15)$$

$\sigma_{\max}$ is then multiplied on both sides of Eq. (12); thus, the SWT parameter can be written as

$$\sigma_{\max}\varepsilon_a = \frac{(\sigma_f^{'})^2}{E}\left(2N_f\right)^{2b} + \varepsilon_f^{'}\sigma_f^{'}\left(2N_f\right)^{b+c} . \tag{16}$$

In the SWT parameter, the maximum stress product controls mean stress effects. This model supposes that at a given life, parameter $\sigma_{\max}\varepsilon_a$ remains constant with the change in maximum stress product and strain amplitude. Parameter $\sigma_{\max}\varepsilon_a$ is originally proposed to consider crack growth and appears to be the most appropriate for gray iron [21].

Recently, Ince and Glinke [10] suggested that only the elastic strain amplitude of the SWT parameter should be corrected to combine the advantages of the Morrow and SWT parameter models. Thus, total equivalent strain amplitude $\varepsilon_{a,eq}$ is given as

$$\varepsilon_{a,eq} = \frac{\sigma_{\max}}{\sigma_f^{'}}\frac{\Delta\varepsilon^e}{2} + \frac{\Delta\varepsilon^p}{2} = \frac{\sigma_f^{'}}{E}\left(2N_f\right)^{2b} + \varepsilon_f^{'}\left(2N_f\right)^{c} , \tag{17}$$

where $\left(\sigma_{\max}/\sigma_f^{'}\right)\left(\Delta\varepsilon^e/2\right)$ is the equivalent elastic strain amplitude and $\Delta\varepsilon^p/2$ is the equivalent plastic strain amplitude. This model provides better life prediction results than the Morrow model for several investigated materials.

As previously mentioned, the SWT parameter is an extension of the mean stress correction SWT method, which is a special case of the Walker mean stress correction method when $\gamma = 0.5$. Therefore, the calculated life prediction results for the SWT parameter will deviate from the test life prediction results when the γ value of a material is far from 0.5.

Although the SWT parameter method has successfully estimated mean stress effects on fatigue life, further works [10, 11, 13, 22, 23] have been conducted to modify the SWT parameter to improve the correlation of mean stress effects. In this study, a modified SWT strain-life method based on the good features of the SWT parameter and the best mean stress correction of the Walker method is proposed. This method can consider the sensitivity of the mean stress of a material.

5. Proposed mean stress correction model

As mentioned in the preceding sections, the Walker method exhibits the best correction of mean stress effects because of its adjustable material parameter γ, which can indicate the sensitivity of the mean stress of the material. The SWT method is a special case of the Walker method when the adjustable material parameter γ is 0.5. Furthermore, the previous section concludes that the SWT parameter is an extension of the SWT method, and that the product of maximum stress $\sigma_{\max}$ is used to control mean stress effects. Simply multiplying $\sigma_{\max}$ on both sides of Eq. (12) is inappropriate. In this study, the sensitivity of the mean stress of a material is constant. In reality, however, the sensitivity of the mean stress of different materials depends on their physical properties. Therefore, material parameter γ should be introduced into the left side of Eq. (16) to describe the control degree of maximum stress $\sigma_{\max}$ on the sensitivity of the mean stress of different materials. Meanwhile, after introducing material parameter γ into the SWT parameter, the modified model must be satisfied. When the γ value of the material is equal to 0.5, the modified model should be simplified to the original SWT parameter. On the basis of the aforementioned conditions, the modified model, which combines the advantages of the Walker material parameter γ and the SWT parameter, is given as

$$2\gamma\sigma_{\max}\varepsilon_a = \frac{(\sigma_f^{'})^2}{E}\left(2N_f\right)^{2b} + \varepsilon_f^{'}\sigma_f^{'}\left(2N_f\right)^{b+c} . \tag{18}$$

Furthermore, as stated in Sec. 3, parameter γ can be expressed as

$$\gamma = 0.5 \pm \frac{\sigma_u - \sigma_o}{\sigma_u + \sigma_o} . \tag{19}$$

Afterward, by combining Eqs. (18) and (19), the final form of the modified model is

$$2\sigma_{\max}\varepsilon_a(0.5 \pm \frac{\sigma_u - \sigma_o}{\sigma_u + \sigma_o}) = \frac{(\sigma_f^{'})^2}{E}\left(2N_f\right)^{2b} + \varepsilon_f^{'}\sigma_f^{'}\left(2N_f\right)^{b+c} . \tag{20}$$

In this study, the selections of the positive and negative values of part $0.5 \pm \left(\sigma_u - \sigma_o \big/ \sigma_u + \sigma_o\right)$ have the same criteria, as stated in Sec. 3. By comparing the modified model with the SWT parameter, the modified model can account for the sensitivity of mean stress of different kinds of materials after introducing material parameter γ into the SWT parameter. Futhermore, the relationship among γ, yield strength σ_o, and ultimate strength σ_u causes material parameter γ to be always available. All these conditions increase the applicability of the modified model in engineering.

6. Validation of the modified model and discussion

In this section, three sets of experimental fatigue data with varying loads and simultaneously varying mean stresses of different materials from super alloy GH4133 [24, 25], aluminum alloy 7075-T651 [26], and carbon steel [6] are used to verify the accuracy and capability of the modified model. Moreover, a comparison is made between the life prediction results calculated using the SWT parameter and the modified model to validate the efficiency of the latter. Table 3 presents a list of monotonic and cyclic properties of super alloy GH4133 [24, 25], aluminum alloy 7075-T651 [26] and carbon steel [6].

By combining Eqs. (16) and (20), the comparisons of the test data and the life prediction results obtained using the SWT parameter and the modified model of super alloy GH4133,

Table 3. Mechanical properties of super alloy GH4133, aluminum alloy 7075-T651 and carbon steel.

	Super alloy GH4133	Aluminum alloy 7075-T651	Carbon steel
Monotonic properties			
Yield strength σ_o	878 MPa	501 MPa	1731 MPa
Ultimate strength σ_u	1221 MPa	561 MPa	2165 MPa
Elastic modulus E	220 GPa	71.7 GPa	205 GPa
Cyclic properties			
Fatigue strength coefficient σ'_f	1796 MPa	1576 MPa	3372 MPa
Fatigue strength exponent b	−0.09	−0.1609	−0.103
Fatigue ductility coefficient ε'_f	0.2527	0.1575	0.038
Fatigue ductility exponent c	−0.56	−0.6842	−0.47

Table 4. Comparison among the lives predicted by the test data, the SWT parameter and the modified model of super alloy GH4133.

σ_{max} (MPa)	σ_m (MPa)	ε_a	Test N_f	SWT N_f	Modified N_f
863	431.5	0.006	1534	2192	1038
864.9	54.8	0.004440	2879	5356	2298
863.4	71.2	0.004365	3720	5688	2424
886.5	85.75	0.004330	2508	5363	2301
734	367	0.004	7778	13337	5128
757	378.5	0.004	6703	11938	4653
743	371.5	0.004	4707	12763	4934
740	370	0.004	6249	12951	4997
761	380.5	0.004	6641	11716	4577
693	346.5	0.0035	12619	27475	9658
704	352	0.0035	11457	25822	9147
735	367.5	0.0035	10734	21841	7899
777.4	100.6	0.003440	8461	18837	6939
743.5	74.2	0.003395	12141	23501	8422
659	329.5	0.003	20852	63994	20318
701	350.5	0.003	19717	49178	16106
686	343	0.003	19411	53886	17457
714	357	0.003	18465	45533	15050
644	322	0.003	23660	70713	22193
672	336	0.0025	44070	132140	38708
647	323.5	0.0025	45090	157420	45285

aluminum alloy 7075-T651, and carbon steel are presented in Tables 4-6 and Figs. 4-6.

According to Tables 4-6 and Figs. 4-6, both the life prediction results of the SWT parameter and the modified model are in good agreement with the test data. Moreover, nearly all of the life prediction results obtained using these two methods are conservative. However, compared with the SWT parameter and considering the introduced material parameter γ, the accuracy of the life prediction results obtained using the modified model has been obviously improved. Thus,

Table 5. Comparison among the lives predicted by the test data, the SWT parameter and the modified model of aluminum alloy 7075-T651.

σ_{max} (MPa)	σ_m (MPa)	ε_a	Test N_f	SWT N_f	Modified N_f
506.2	152.5	0.0050	2862	2212	3082
506	221.3	0.0041	6144	3847	5409
536.3	268.2	0.004	5275	3500	4915
440	159.9	0.004	12288	6147	8697
440.1	220.0	0.0032	17885	11754	16744
401	200.5	0.0029	34956	20711	29638
355.3	177.7	0.0025	54680	46483	66832
293.2	146.6	0.0021	209237	141670	204530
237.4	118.7	0.0017	1283826	518480	750500
507.8	432.1	0.0011	245801	190890	275800

Table 6. Comparison among the lives predicted by the test data, the SWT parameter and the modified model of carbon steel.

σ_{max} (MPa)	σ_m (MPa)	ε_a	Test N_f	SWT N_f	Modified N_f
1659	1171	0.0025	58040	162860	64674
1704	1123	0.003	14670	61695	24897
1322	645	0.0035	28090	97820	39152
1904	1165	0.004	5640	10204	4304
1519	703	0.004	19030	28017	11498
719	-337	0.005	40230	318650	125460
1058	0	0.005	23133	52709	21336
986	0	0.005	15492	72923	29337
1653	664	0.005	4070	7132	3044
1907	942	0.005	2240	3856	1682
970	-308	0.006	23860	34065	13917
1226	0	0.007	1727	6057	2599

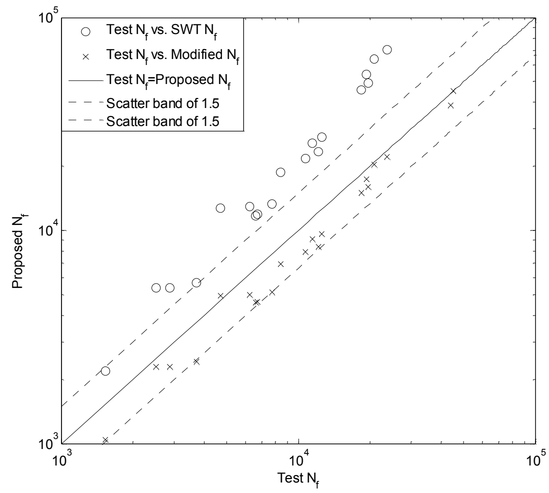

Fig. 4. Predicted life vs. tested life of super alloy GH4133.

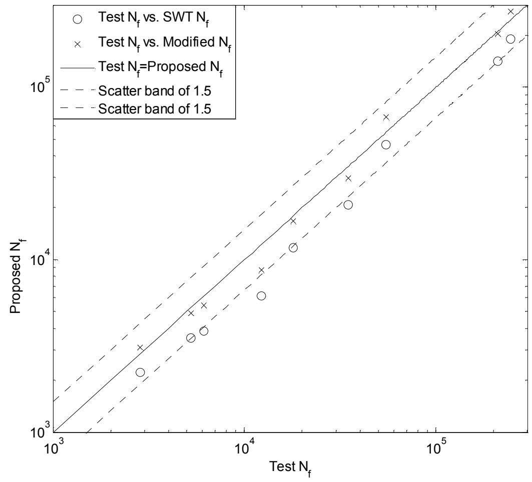

Fig. 5. Predicted life vs. tested life of aluminum alloy 7075-T651.

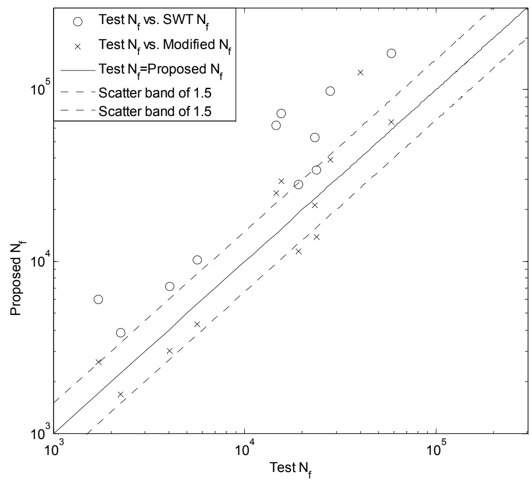

Fig. 6. Predicted life vs. tested life of carbon steel.

the modified model yields superior life prediction results than the SWT parameter. From Eq. (9), the corresponding calculated material parameter γ values of super alloy GH4133, aluminum alloy 7075-T651, and carbon steel are 0.663, 0.4435, and 0.61, respectively. The SWT parameter provides more accurate life prediction results for aluminum alloy 7075-T651 than for super alloy GH4133 and carbon steel because the material parameter γ value of aluminum alloy 7075-T651 is closer to 0.5. For the modified model, all the life prediction results fall within the scatter band range of ±1.5 because material parameter γ, which can represent the sensitivity of the mean stress of materials, and the modified model always provide reasonable life prediction results for the three kinds of materials.

7. Conclusions

The Walker method is currently the best mean stress correction technique because its adjustable material parameter γ can be used to describe the sensitivity of the mean stress of a material. However, the unavailability of material parameter γ limits the application of this method in engineering. To solve this problem, the relationship among material parameter γ, yield strength σ_o, and ultimate strength σ_u is determined in this study, and a practical method is proposed to calculate material parameter γ. The test data then demonstrate that the proposed practical method is acceptable.

The SWT parameter is the most widely used strain-life method; however, it also exhibits a disadvantage, that is, it regards the sensitivity of the mean stress of different materials as a constant. Therefore, material parameter γ, which can be used to describe the sensitivity of the mean stress of a material, is introduced into the SWT parameter in this study, A modified model is then proposed. Three sets of experimental fatigue data demonstrate that the life prediction results obtained using the modified model are in good agreement with the test data. Furthermore, a comparison between the SWT parameter and the modified strain-life model indicates that the latter provides better life prediction results than the former.

Acknowledgment

The authors would like to acknowledge the support provided by the National Natural Science Foundation of China under contract number U1330130.

Nomenclature

σ_a	: Stress amplitude
σ_m	: Mean stress
$\Delta\sigma$	: Stress range
R	: Stress ratio
σ_{ar}	: Equivalent stress amplitude at zero mean stress
σ_u	: Material ultimate strength
σ_{fB}	: True fracture strength
γ	: Material parameter
ψ	: Reduction in area
ε_e	: Elastic strain amplitude
σ_f'	: Fatigue strength coefficient
E	: Elastic modulus
N_f	: Fatigue life
b	: Fatigue strength exponent
ε_p	: Plastic strain amplitude
ε_f'	: Fatigue ductility coefficient
c	: Fatigue ductility exponent

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