Twist Fatigue Life Simulation and Correlation with Test for an Automotive Rear Suspension

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Abstract

This paper documents the result of twist fatigue life simulation correlated with test for an automotive rear suspension. The simulations were performed on both accelerated and standard twist test under constant amplitude cyclic loading. The accelerated twist test was developed for correlation. The result shows that the analytical fatigue life correlates with the test fatigue life within a factor of 2. However, the experiment shows that a crack appears exactly at the v–reinforcement tips to the weld toes as simulation predicted. It is observed that the welds are an important factor in this simulation and rigid modeling is feasible. This project also serves as a case study to the students in predicting fatigue failure of a real industrial part.

1 Introduction

As shown in Fig. 1, a typical automotive rear suspension consists of the v-beam, v-reinforcement, stabilizing bar, spring seat, spring seat reinforcement, jounce and jounce stop, knuckle, spacer, shock mount, shock nut, trailing arm, sleeve and bushing. These components are assembled through bolts and welds. Due to normal use of the vehicle and exceptional road conditions, it is essential to perform durability analysis in the rear suspension.

The objective of this work is to develop a durability analysis procedure of an automotive rear suspension component under twist loads. Due to driving and road conditions, twist load is common to rear suspension. The first step is to apply linear stress analysis to determine the regions with high possibility of failure, based on displacement and stress distributions, on the suspension components. Then the strain-life/signed von Mises stress approach [1] is used to perform the fatigue analysis at these critical regions. The simulations were performed on both accelerated and standard twist test under constant amplitude cyclic loading.

The developed procedure is capable of predicting the fatigue life and potential crack area on the suspension under cyclic twist loading. Experiments are carried out to validate and correlate with the predicted results. In addition to the procedure development, this project also serves as a case study for students in predicting fatigue failure of a real industrial part.

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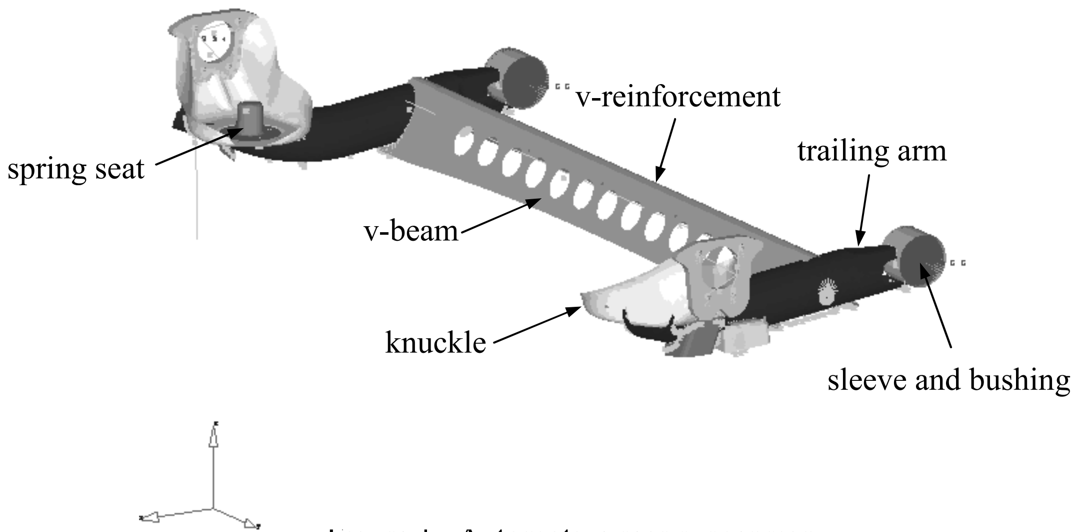


Figure 1. Automotive rear suspension

2 Model Development

This section gives an overview of the analysis model, boundary and loading conditions for an automotive rear suspension component.

2.1 Analysis Model

A Finite Element (FE) model of the rear suspension component is constructed for analysis. Hypermesh [2] is used as a pre- and post-processor to generate the finite element model and review the results. Nastran [3] solver is used to obtain the stress and displacement results. The v-beam, v-reinforcement, spring seat, spring seat reinforcement, jounce and jounce stop, spacer, shock mount, trailing arm and sleeve are meshed as shell elements, while the knuckle and shock nut are meshed as solid elements. Bar elements are used to model the stabilizing bar. Spring elements represent the bushing associated with the sleeves and rigid elements represent welds. The number of elements in the model is 28816, and the number of nodes is 29,534. The number of the 2-D elements is 25,571. The element size ranges from 3 to 6 mm. The attributes of the elements are summarized in Table 1.

2.2 Constraint and Loading Conditions

Two sleeves are respectively constrained at their central positions. All six degrees of freedom of the central positions are constrained. Spring element is used to model the bushing associated with the sleeve at the center. The central position is connected to the sleeve through the rigid elements which represent the bushing-hinged supports.

For the standard twist test, constant amplitude out-of-phase displacements of ±61 mm are applied at the centers of the two knuckles. These centers are connected with the knuckle through the rigid elements. For the accelerated twist test, constant amplitude out-of-phase displacements of ±92 mm, a 50% increase over those of the standard twist test, are applied.

Table 1. Summary of element attributes

element			warpage				skew				Jacobian			
Type	No.	size	whole model		critical region		whole model		critical region		whole model		critical region	
		mm	>5º	Max	>5º	max	>60º	max	>60º	max	<0.70	min	<0.70	min
2-D	25571	3~6	3%	10º	0	5º	0	52º	0	51º	2%	0.65	3%	0.65
3-D	2046	4~6	2%	22º	NA	NA	0	39º	NA	NA	8%	0.61	NA	NA

2.3 Material Properties

The critical locations are identified as the central section of the v-beam and the v-reinforcement tips to the weld toes. The v-beam and the v-reinforcement are made of HSLA080X and HSLA050X, respectively. The fatigue properties and tensile properties are listed in Table 2 [4]. Spring elastic constants of bushing in the directions of the six degrees are respectively 1,100 N/mm, 1,650 N/mm, 600 N/mm, 1,317,803 N-mm/radian, 300,803 N-mm/radian and 1,260,507 N-mm/radian.

Table 2. Fatigue and tensile properties of materials

material	Fatigue Properties						Tensile Properties		
	Ductility coeff.	Strength coeff.	Ductility exponent	Strength exponent	Strength coefficient	Strain hardening	Ultimate strength (MPa)	Yield strength (MPa)	Elongation (%)
080X	0.21	1054.9	-0.53	-0.08	1248.0	0.134	693.9	628.6	22
050X	0.35	627.4	-0.54	-0.075	792.9	0.134	480.9	381.3	36

2.4 Assumptions and Limitations

The major assumptions in this study are: 1) linear elastic materials with small displacement are applied in stress analysis, 2) welds are modeled as rigid elements, and 3) spring elements are used to model the bushing associated with the two sleeves. The strain-life/signed von Mises stress approach and Miner's linear damage rule [5] are applied in the fatigue analysis. The Miner's rule is described in the next section.

In order to ensure the linear analysis is effective, both the physical and geometric linear relationships are essential. It is not recommended to increase the applied displacements more than 92 mm.

3 Analysis Procedure

The outputs of static linear stress/strain analysis are the stress and displacement distributions that are used to determine the critical regions. The fatigue analysis applies a software package, CFS [6], which is a strain-based fatigue program to determine the life to crack initiation for a component under a variable amplitude history. The CFS accounts for mean stresses using either the Smith-Watson-Topper or Morrow strain-life equation. The inputs for CFS are: 1) the peak and valley stresses under the loads at the critical regions and 2) the element numbers and the fatigue properties of the material.

When a cycle is found by the cycle counting algorithm, CFS calculates the damage for that cycle. Damage is defined as the inverse of life. If a component will survive 100 cycles at a given stress, then the damage per cycle is 1/100=.01. The damage for each cycle is summed to obtain the damage for the entire history. This is known as Miner's rule. The total damage is then inverted to obtain the life for the variable amplitude history. If the damage is 1.0, then the component has initiated a crack during that history. The flow chart of analysis is shown in Fig. 2.

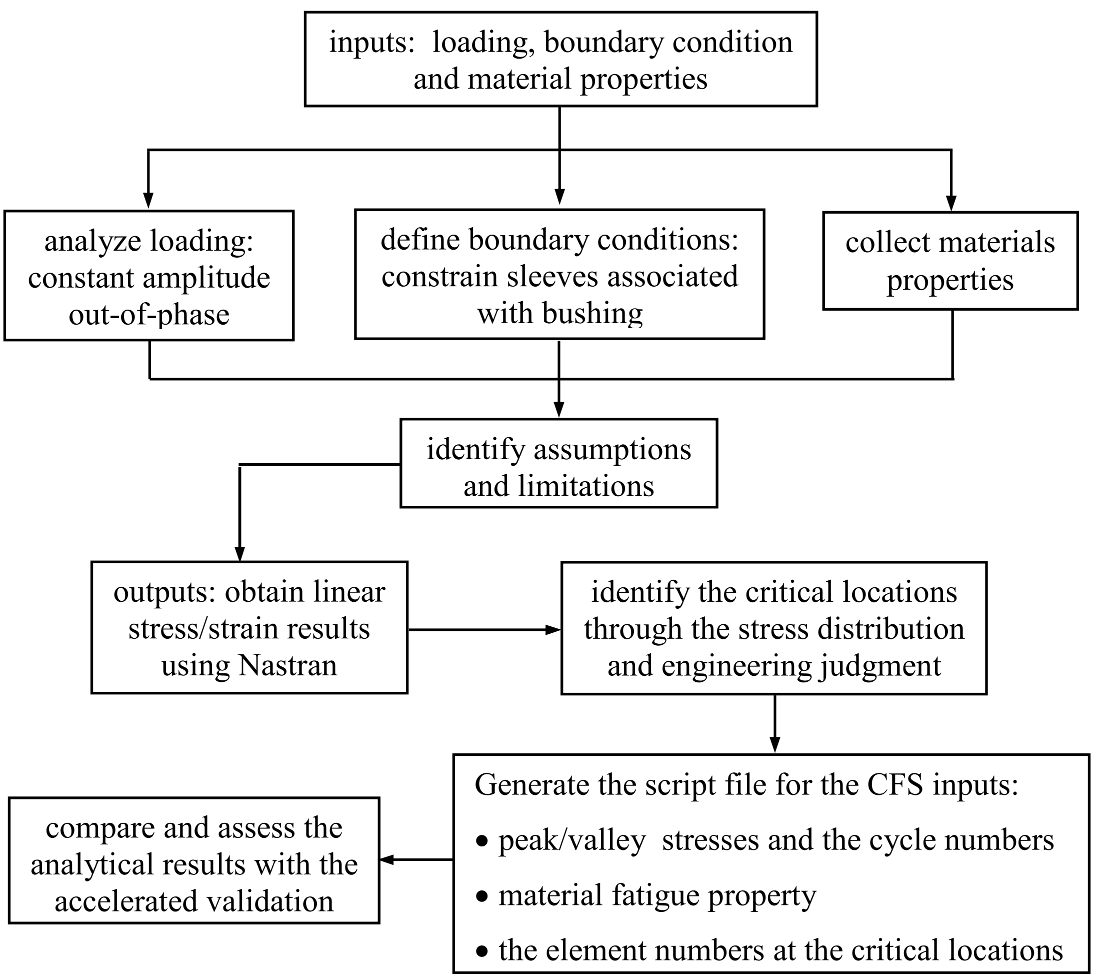


Figure 2. Flow chart of analysis procedure

4 Simulation Results

Figure 3 shows a displacement distribution in the z-direction. The maximum von Mises stress distribution is shown in Fig. 4. The critical locations, from the linear static stress analysis, are identified as the central section of the v-beam (at element 24955 with 380 MPa), and both right and left v-reinforcement tips to the weld toes (at element 9885 with 302 MPa). Although a higher von Mises stress level happens in the central section of the v-beam, both the right and the left v-reinforcement tips to the weld toes could be potential failure locations. This is because the fatigue properties of material HSLA080X used in the v-beam are superior to those of material HSLA050X used in the v-reinforcement (see Table 2). Generally, the rear suspension structure consists of more than one material. For different materials with different fatigue properties, a lower stress level does not necessarily result in less damage. Furthermore, the weld sites are often weak links and should be addressed.

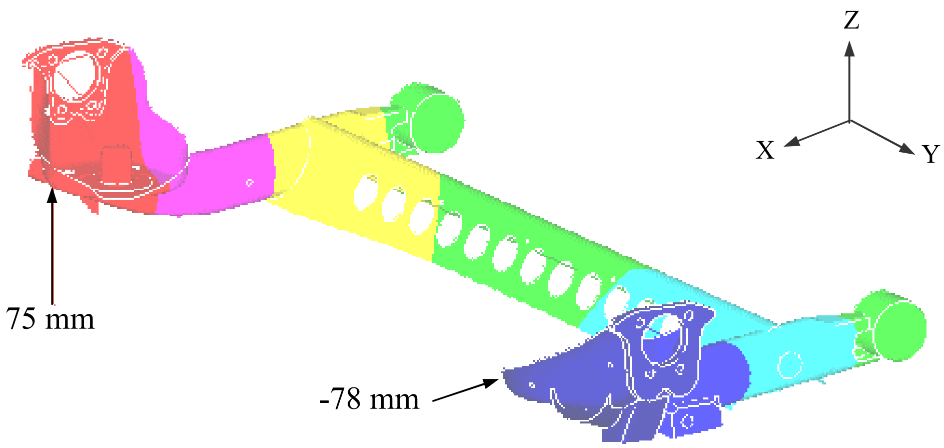


Figure 3. Displacement distribution in z-direction

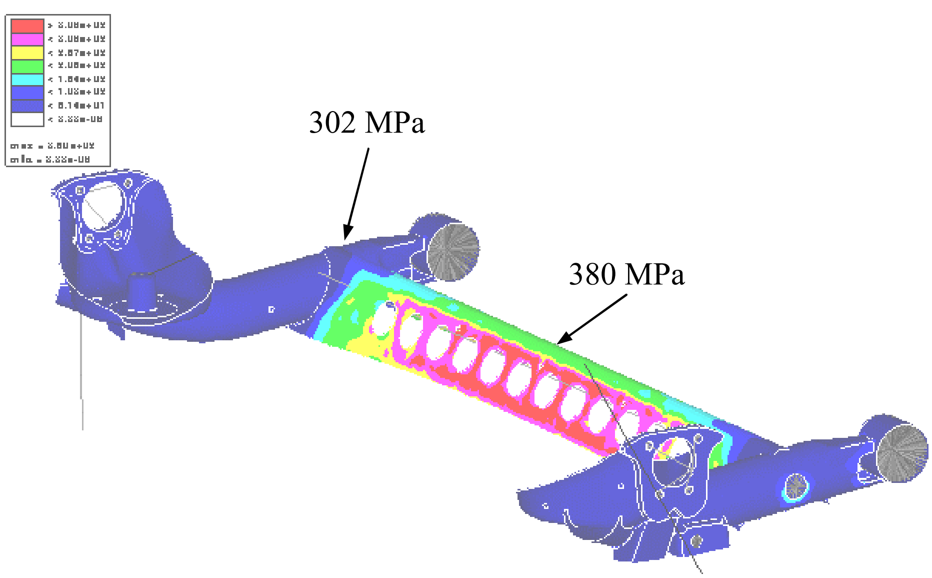


Figure 4. All maximum von Misses stress distribution

The modeling of welds in sheet-metal assembly plays an important role in determining the structure stiffness. It has been proved that the predicted results are sensitive to how the welds are modeled [7-9]. The modeling of the rigid welds might lead to high stress around the welds. It is also observed that a predicted higher stress level might not represent the actual stress level. The predicted stress level highly relies on the density of mesh in FE model. For example, one model with fewer numbers of nodes on certain area might cause concentrated high-level stresses on those nodes. Placing a triangle element at the critical location might also generate a higher stress in the triangle element. Consequently, the triangle elements should be avoided at the critical regions. In an inevitable transition area, the triangle elements should be meshed as far away from the critical locations as possible. Those fictional high stresses would be misleading to discard the real high stresses. Generally, the rear suspension structure consists of more than one material. For different materials with different fatigue properties, a lower stress level does not necessarily result in less damage.

5 Correlation With Test

Both the loading configuration and boundary conditions of the accelerated twist test are the same as those of the standard twist test, except that the out-of-phase displacements applied were increased by 50% to speed up the tests. Out-of-phase displacements of ±92 mm are applied at the centers of the two knuckles. Two sleeves were respectively constrained at their centers through the bushing. The accelerated twist test fixture is shown in Fig.5. The rear suspension was inspected every 1000 cycles, and the accelerated twist test was run until the rear axle cracked. A rosette was gauged at the central section of the v-beam, as shown in Figs. 6a and 6b, to determine the correlation with the analytical strains.

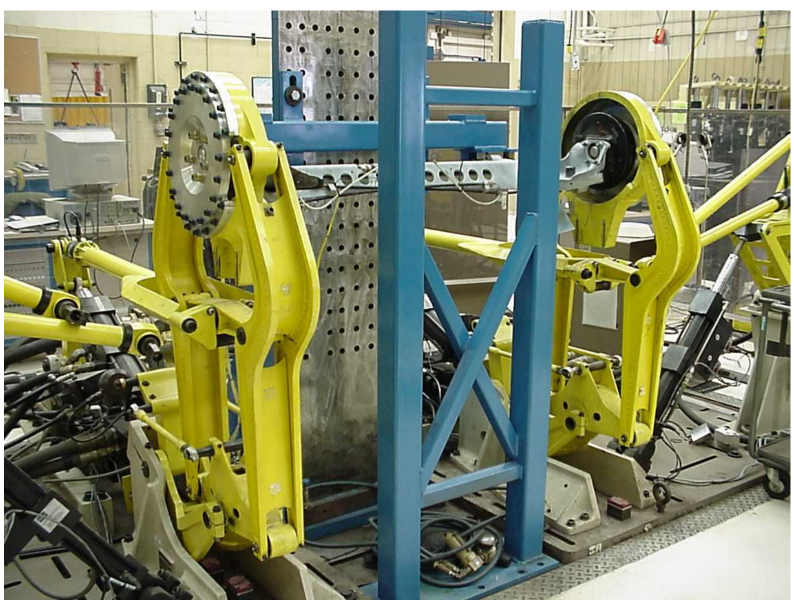
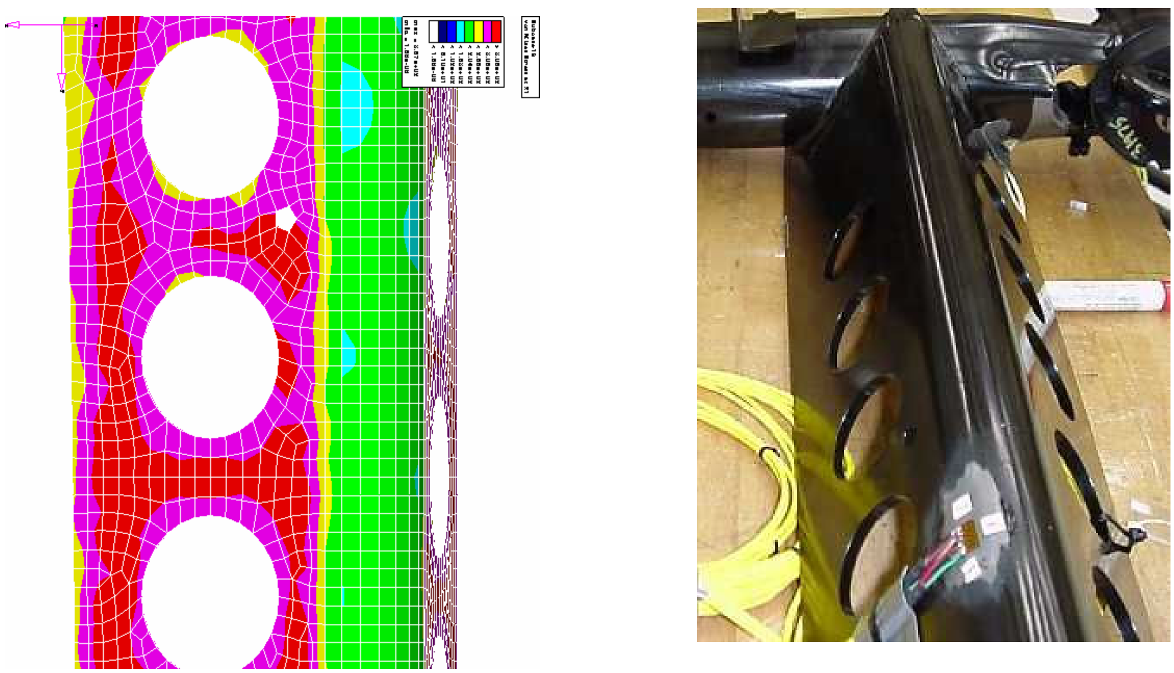


Figure 5. Experimental fixture of rear suspension for the twist simulation

Cracks of 1 mm at both the right and left reinforcement tips to the weld toes were detected at 27,000 cycles, and the cracks grew up to 3 mm after 45,000 cycles. The fatigue life analytical simulation estimates a fatigue life of 24,700 cycles. The predicted fatigue life correlates with the tested fatigue life within a factor of 2. A comparison of the predicted and tested fatigue lives is listed in Table 3. The failures, as predicted, appeared exactly at both the right and left reinforcement tips to the weld toes. Figure 7a shows the failure site at the right v-reinforcement tip to the weld toe, while Fig. 7b presents the predictions – the all-maximum von Mises stress distribution in the area of the right V-reinforcement tip to weld toe. The analytical strains correlate with the experimental measurements at the central section of the v-beam (element 24731), within a factor of 2.0. The analysis gives the lower strain levels. A comparison of the predicted and the measured strains in the above location is listed in Table 4.



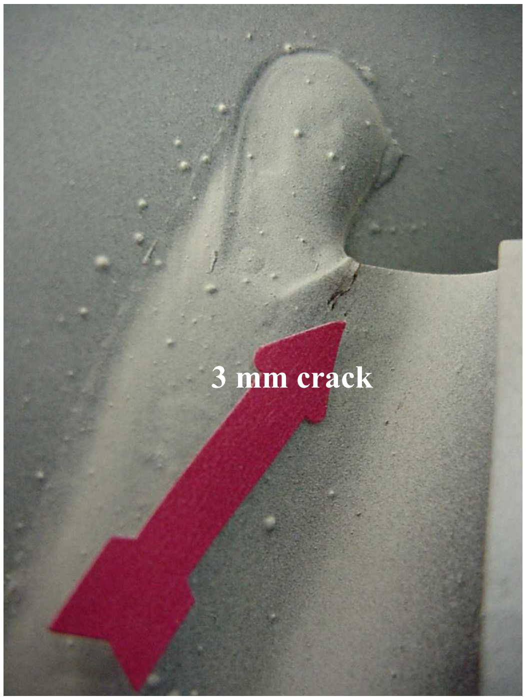
6a. Rosette at the v-beam central section

6b. Rosette location local view-element 24731

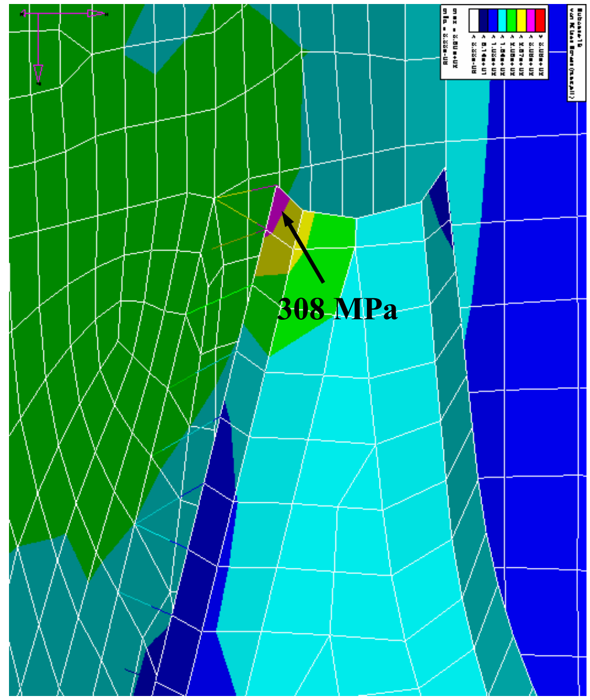
Figure 6. Rosette location and the von Missies stress distribution in the central section of the v-beam

Table 3. Comparison of predicted and measured strains under accelerated twist test

Location	major strain			minor strain		
	Measured	predicted	measured/ predicted	measured	predicted	measured/ predicted
element No. 24731 (v-beam middle)	1242	619	2.0	−1294	−619	2.1



7a. 3 mm crack of after 45,000 cycles



7b. Maximum von Misses stress distribution

Figure 7. A crack of 3 mm at the location of v-reinforcement tip to the weld toe after 45,000 cycles

Table 4. Comparison of predicted and test fatigue lives under accelerated twist test

Test	cyclic max/min displace-ment (mm)	cyclic max/min stress (MPa)	freq. (Hz)	predicted fatigue lives (cycle)	tested fatigue lives (cycle)		tested / predicted	predicted failure location	tested failure location
					1 mm crack	3 mm crack			
accele-rated twist	92 / –92	301 / –301	0.5 ~1.0	24,700	27,000†	45,000‡	1.82	v-reinforce-ment tip to weld toe	v-reinforce-ment tip to weld toe

Conclusions

This paper develops a procedure that is capable of predicting fatigue life and potential crack area on an automotive rear suspension under cyclic twist loads. The first step is to apply linear stress analysis to determine the regions with high possibility of failure, based on displacement and stress distributions. Then the strain-life/signed von Mises stress approach is used to perform the fatigue analysis at these critical regions. Experiments are also carried out to validate and correlate with the predicted results.

Both simulation and experiment identify that critical regions are identified as the central section of the v-beam and both right and left v-reinforcement tips to the weld toes. The predicted fatigue life is about 1.8 times of the tested fatigue life. However, the experiment shows that a crack appears exactly at the v–reinforcement tips to the weld toes as simulation predicted.

Modeling techniques are also discussed in terms of high-level stress evaluation. The modeling of welds and element mesh density of a FE model play an important role in determining the critical regions under cyclic twist loading. The triangle elements should be avoided at the critical regions. In an inevitable transition area, the triangle elements should be meshed as far away from the critical locations as possible.

In addition to the procedure development and correlation with test, this project also serves as a case study to the students in predicting fatigue failure of a real industrial part.

References

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Biography

GENE LIAO, currently an assistant professor at the Wayne State University, received his B.S.M.E. from National Central University, Taiwan, M.S.M.E. from the University of Texas, Mechanical Engineer from Columbia University, and the Doctor of Engineering degree from the University of Michigan, Ann Arbor. His research and teaching interests are in the areas of mechanical design, multibody dynamics, and CAE applications in manufacturing. Dr. Liao has 15 years of industrial practice in the automotive sector prior to becoming a faculty member.