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ANALYSIS FOR THE EFFECT OF SHAPE OF CRIMPED PORTION UPON THE SEALING PERFORMANCE OF HYDRAULIC BRAKE HOSE BY THREE-DIMENSIONAL FEM

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Usually, automobile high-pressure hose, such as hydraulic brake hose, has been developed through investigating several actual prototype hoses experimentally. Recently, high durability for brake hose has been required because periodic renewing the brake hoses has not been requested anymore. In this study, FEM stress analysis has been applied to the crimped portion of hydraulic brake hose in order to promote the development of the automobile hoses more efficiently. The sealing performance is discussed focusing on the normal stress between the nipple and inner rubber with varying several important geometrical dimensions of crimped portion.

Keywords: *Stress analysis, Finite Element Method, Sealing Performance, Brake Hose, Automobile*

1 Introduction

In order to conduct the oil pressure generated by the master cylinder to the brake, hydraulic brake hoses are installed between the body and chassis in automobiles. They are supposed to be always flexible under complex external loads such as lateral vibration from the road, torsion from steering wheel, and impact oil pressure during braking. In recent years, brake hoses are arranged in a smaller space because anti-lock brake system and complex link mechanism for high grade suspension are newly introduced. Although brake hoses used to be changed periodically, a new regulation enacted in 1995 has not asked this regular renewing anymore for personal automobiles, and therefore, high durability of brake hose is necessary. In addition, to pursuit comfortable driving, low expansion of brake hoses is also requested in terms of quick response during braking.

The brake hose consists of inner rubber, reinforced layer, and outer rubber as shown in Fig. 1. Caulking of brake hose is caused by crimping of socket after inserting brake hose. Since rubber material has high flexibility with no volume change, which is called incompressibility, high compressible stresses appear between the nipple and inner rubber, which causes high sealing performance at the caulking portion. Usually, development of automobile brake hose has been realized by evaluating a lot of materials and shapes of nipple and crimping socket experimentally.

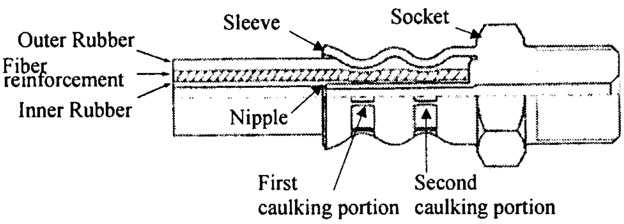

Figure 1: Hydraulic brake hose with crimping

In this study, therefore, stress analysis by FEM will be performed for the crimped portion of hydraulic

Table1: Material data used in FEM analysis

	Material	Young's modulus (MPa)	Poisson's ratio
Outer Rubber	EPDM	Use of experimental data	Use of experimental data ($\nu \cong 0.45$)
Inner Rubber	EPDM	Use of experimental data	Use of experimental data ($\nu \cong 0.45$)
Fiber reinforcement in the r-direction	PVA	40	0.2
Fiber reinforcement in the θ- and z-directions	PVA	100	0.2
Sleeve	S10C (JIS)	207000	0.29
Nipple and Tool		Rigid body	

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pressure brake hose in order to promote the development of the automobile hoses more efficiently.

2 Condition of Analysis

Usually the stress-strain relation of rubber is expressed by using Mooney-Rivlin material model, Ogden material model, or Arruda-Boyce material model. In this study, Arruda-Boyce material model is applied.

The reinforced layer is composed of a complicated net structure of Polyvinyl Alcohol (PVA) material. It is very difficult to consider of wire reinforced layer each other on analysis software.

In this study, therefore, the reinforced layer is modeled as an anisotropic elastic material whose elastic constants are E_r, E_θ=E_z, $v_{r\theta}$, $v_{\theta z}$, v_{zr}. Most suitable elastic consultants will be found from the displacement at the caulking portion assuming that these three layers are bonded completely.

The hose is composed of three types of layer on outer rubber, fiber reinforcement and inner rubber.
The coefficients of friction are assuming to be 0.3 between outer rubber and sleeve, and between inner rubber and nipple. Table 1 shows materials and elastic constants of each layer.

The sealing performance of brake hose is evaluated by contact normal stress σ_r between inner rubber and nipple.

3 The Effect of Shape of Crimped Portion on the Sealing Performance

Figure 2(a) shows an example shape of real crimped portion of brake hose. Two regions are caulked with a tool whose width $_{crimp}$ is $_{c0}$. This shape is designed on the basis of experiments and experiences. Here, we consider the optimal shape of crimped portion by FEM analysis focusing the caulked length, number of caulked portion, distance between tools, and depth of caulking, which may affect the sealing performance.

3.1 The Effect of Calked Length on the Sealing Performance

Figure 2(a)-(c) shows FEM models to investigate the effect of caulked length on the sealing performance. Figure 2(b), (c) considers one caulked region with different caulked length. The depth of caulking is always Δu_{r2}, which is the same amount of Fig. 2(a). The caulked length of FEM models are $_{c0}$ and $_{c1}$, and evaluate contact normal stress between inner rubber and nipple.

Figure 3 shows relationship between σ_r and the caulked length when the caulked length $_{crimp}$ is $_{c0}$ as shown in Fig. 2(b) and l_{c1} in Fig. 2(c). Three lines show contact normal stress σ_r between inner rubber and nipple for Fig. 2(a-c). From Fig. 3, it is seen that the region of large stress σ_r increases with the increasing caulked length. Also, it is found that the maximum value of σ_r increases with increasing the caulked length. It may be concluded that large caulked length increases the maximum value of σ_r as well as the region of large stress σ_r.

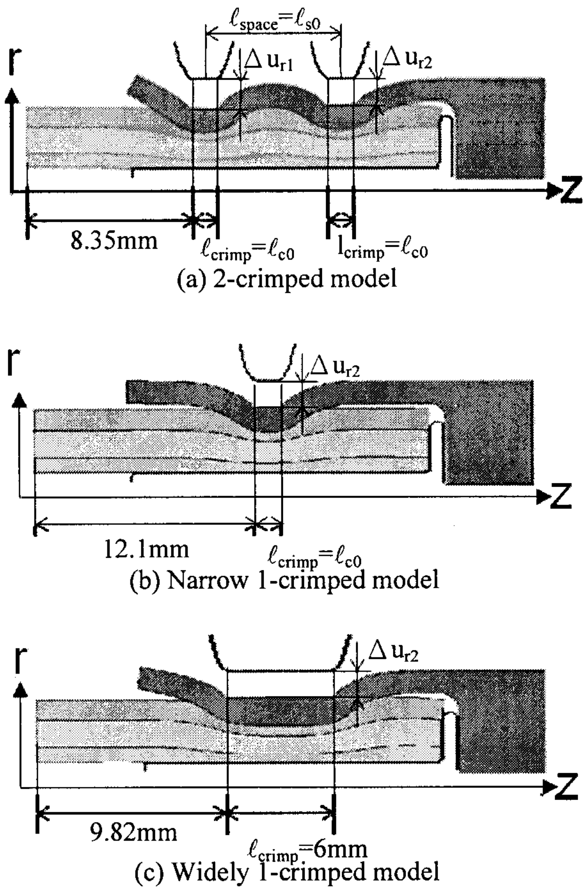


Figure 2: Model for the effect of caulked length

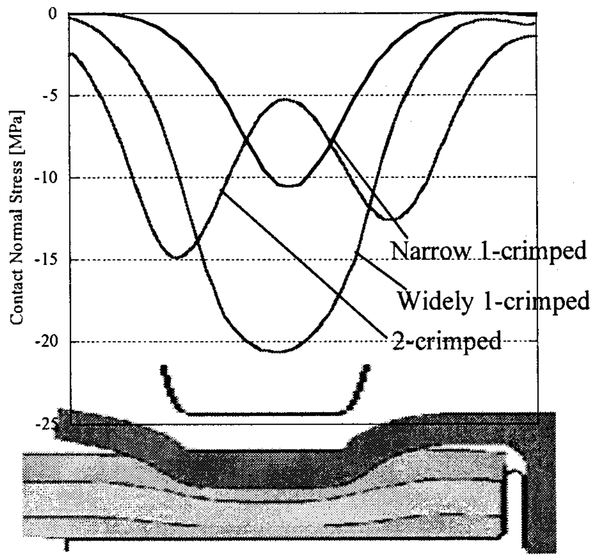


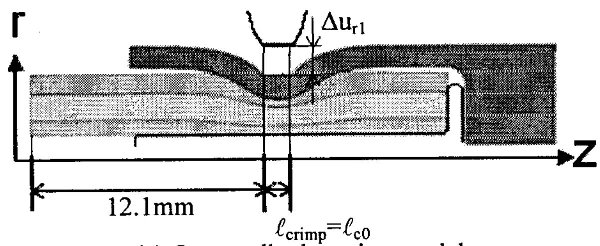
Figure 3: Relationship between σ_r and caulked

3.2 The Effect of Number of Calked Portion on the Sealing Performance

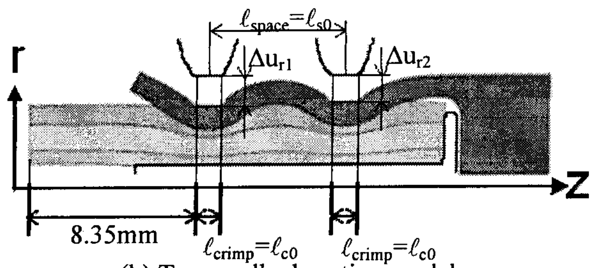
Figure 4(a) (b) (c) shows FEM model for the effect of number of caulked portion on the sealing performance. The Ccaulked length $_{crimp}$ is constant as

$_{c0}$. In Fig. 4(c), the amount of caulking depth is Δu_{r1} at the first caulked portion, Δu_{r2} at the second caulked portion, and Δu_{r3} at the third caulked portion. Considering the real brake hose in Fig. 2(a), the sealing performance is investigated from the normal stress between inner rubber and nipple for different number of caulked portion as shown in Fig. 4(a-c).

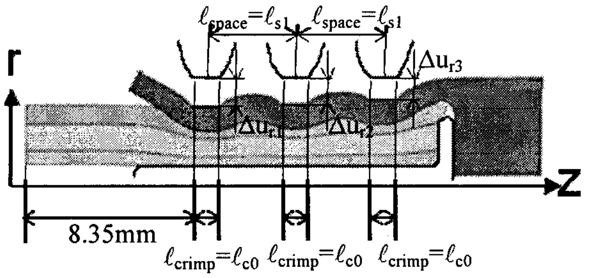
Figure 5 shows the contact normal stress between



(a) One caulked portion model



(b) Two caulked portion model



(c) Three caulked portion model

Figure 4: Model for the effect of number of caulked portion

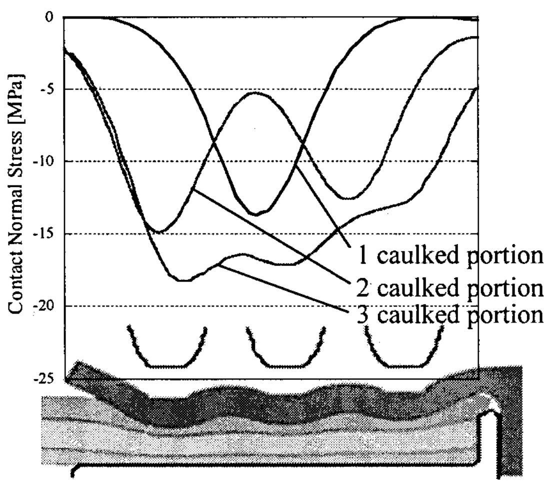


Figure 5: Relationship between σ_r and number of caulked portion

inner rubber and nipple for the models in Fig. 4(a-c). It is seen that although the caulked depth Δu_{r1} is the same at the first portion σ_r increases with increasing the number of caulked portions. It may be concluded that increasing the number of caulked portions results in the larger value of σ_r as well as the wider regions of σ_r.

4 The Effect of Manufacturing Error on the Sealing Performance

Table 2 shows an example of three kinds of three-dimensional models considering eccentricity and inclination in real brake hose. In order to investigate such manufacturing error on the sealing performance, those three kinds of models are considered and a 3D FEM analysis is performed.

In order to reduce the calculation, we assume the rigid sleeve having has the final shape of the deformation (see Fig. 2(a)). Then the three-layered brake hose is to be clamped by the rigid sleeve.

Figure 7 shows the effects of eccentricity and inclination on the normal stress σ_r between nipple and inner rubber. Solid line of Fig. 7(a) shows the normal stress σ_r for no eccentricity and no inclination. Maximum stress of first crimped portion is estimated by 14.5MPa. It is found that 3D model of stress coincides with that of axi-symmetric model in Fig. 2(a) with less than 0.1% error.

Figure 7(b) and Figure 7(c) show the normal stress σ_r when the nipple has an eccentricity $e = e_1$ and an inclination $\theta = \theta_1$. Here, since the eccentricity and inclination cause asymmetric stress distribution of σ_r, the maximum and minimum stress distributions at the upper and under parts along the nipple are indicated in Fig. 7(b) and Fig. 7(c). Also these figures indicates the

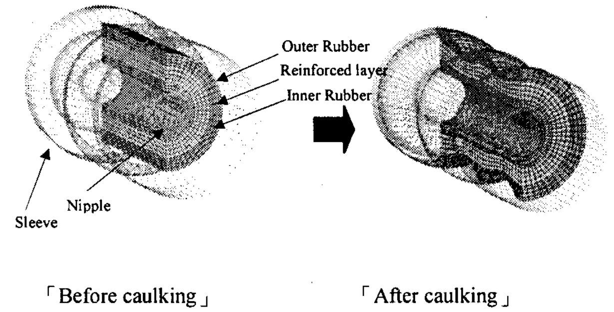


Figure 6: FEM model for 3D Analysis

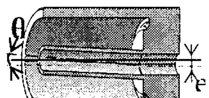
results for $e = \theta = 0$ as dotted lines for comparison.

To discuss the effect of manufacturing error on the sealing performance, the difference between the results for $e = e_1$, e=0 should be discussed became the sealing performance may be controlled by the maximum normal stress σ_r. (see Fig. 7(b))

From Fig. 7(b), it is seen that the maximum normal stress decreases by 31% at the first portion and by 33% at the second portion when $e = e_1$, θ=0 It is found that the eccentricity causes deterioration of sealing performance.

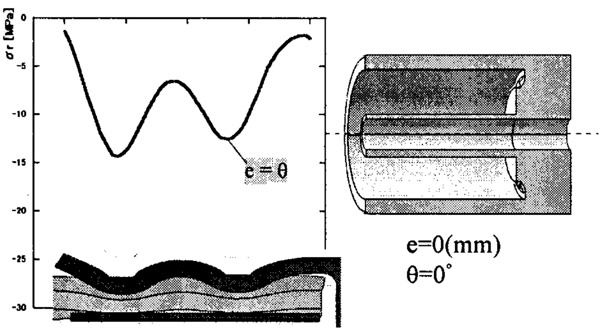
Table2: Dimensions of models for manufacturing error

		Eccentricity e(mm)	
		0.00	e_1
Inclination angle θ(°)	0.00	CASE1	CASE2
	θ_1	CASE3	—

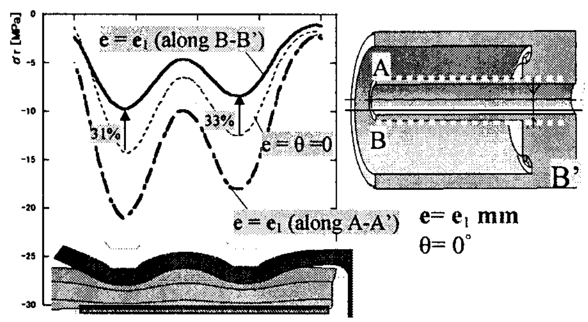


「Here, e_1, θ_1, are larger than the upper limit of

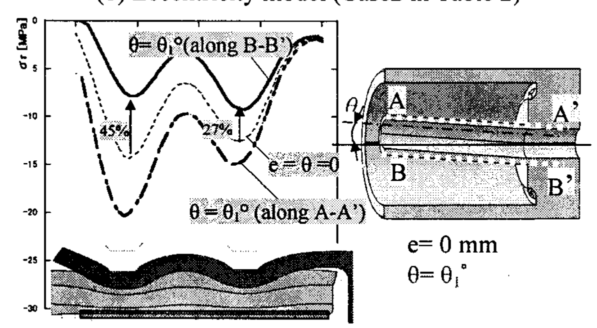
Figure 7(c) shows that the maximum normal stress decreases by 45% at the first portion and by 27% at the second portion when e = 0 , θ= θ1. From these results it



(a) Normal model (Case1 in Table 2)



(b) Eccentricity model (Case2 in Table 2)



(c) Inclination model (Case3 in Table 2)

Figure 7: Effect of dimension e and angle θ on σ_r investigative manufacture error

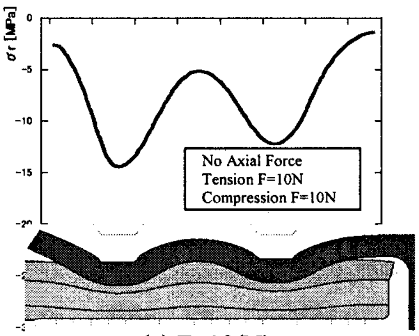
is found that the manufacturing error may causes deterioration of sealing performance of hydraulic brake hose.

5 The Effect of External Force on the Sealing Performance

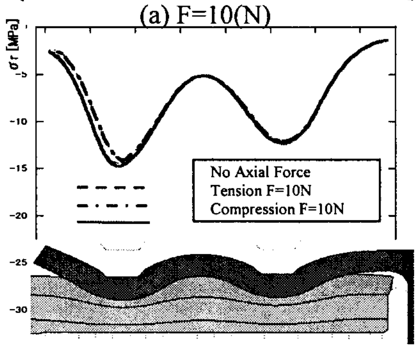
The brake hose installed to automobiles is usually subjected to several types of loads such as vibration due to road surface-wave, and tensile forces due to steering wheel. In this study, the effects of those forces on the sealing performance are investigated through FEM analysis.

Sealing performance is examined when tensile force is applied to the brake hose. Here, the tensile force is assumed as 10N and 100N by using the axi-symmetric FEM model. The results are show in Fig. 8.

It is seen that the effect of tensile force is not very large because σ_r does not change very much. It may be concluded that the effect of external force on the sealing performance is not very large.



(a) F=10(N)



(b) F=100(N)

Fig.8 Effect of axial force F on σ_r

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