A Study on The Effect Of Defect Location On Stress In Bending Pipe

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Abstract: In this study, the stress that generated when the first or second root of a corrugated pipe is defective is analyzed. The model is analyzed using F.E.M. code. The boundary conditions of deflection or torsion on the opposite side of the defect in the corrugated pipe are changed. The effect of the defect is evaluated using the change of the stress magnitude and the stress concentration factor(K) according to those conditions. As a result of comparing the stress magnitude, K around the flaw at the secondary root is larger than K around the flaw at the first root. Based on the position of the defect, the stress difference in the 1st root increases depending on the boundary condition of bending deflection. However, when the 2nd root is defective, the stress magnitude is similar in both cases regardless of the bending deflection. The magnitude of the stress generated in the corrugated pipe is the highest when the second root is defective. And the stress magnitude is the lowest when there is no defect. In the absence of defects, the stress gradually increases after the stress reaches the minimum value as the amount of deformation increases. However, if there is a defect, stress continues to increase, and when it passes through the plastic zone, the stress gradually increases.

Keywords: Deflection, Numerical Analysis, Stress Concentration, Von-Mises Stress.

1. Introduction

The effect of defects on machine parts or structures under load is not negligible. If a crack is present around the flaw, it will grow to flaw. If flaws become large, the crack is directed toward flaws further. As the evolving crack propagates near the defect, the crack path is directed toward the direction of the defect. When advancing crack is distant from the defect, the degree of bending to the defect gradually decreases [1].

There are many flaws in materials. Micro flaws will affect the mechanical properties. The failure of the material follows a process in which cracking begins, propagates and fracture under external loads. Defects such as holes and cracks will affect the material's failure. Failure mechanism of defective material with varying load is very complex and it is great interest [2]. Dynamic behaviors of cracks have been studied [3,4]. A lattice spring model was studied for S.I.F. of a crack tip through a machined hole [5]. The material with defects is failed by several factors. If there are crack and defects, the continuous cracks directly penetrate the defects [6]. Main crack created by the dynamic breakdown of the material generally do not penetrate directly, but propagate the area near the defect.

Among industrial component parts, the bending corrugated pipe has the low stiffness compared to a straight pipe with same properties and cross-section, so that stress and strain are greatly increased, and it is easy to fail. In particular, in the case of a bending corrugated pipe that is exposed to a condition in which load or displacement change during dynamic loading, stress change occurs as shown in Figure 1 as the curvature of the corrugation and the curvature of the entire pipe change. It acts as a fatal factor for the stiffness of the tube.

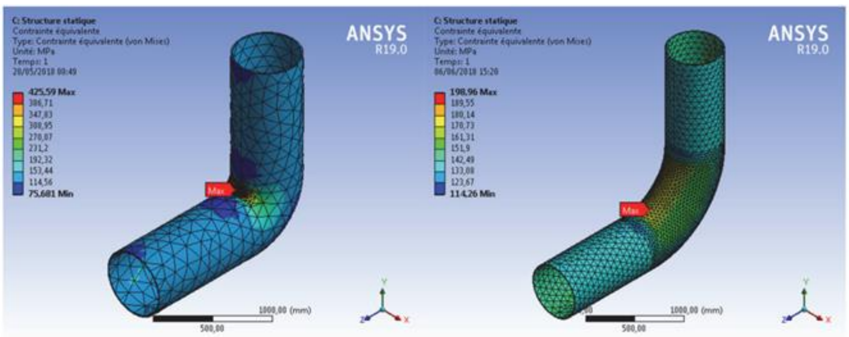

Figure 1. The difference in stress according to the radius of curvature [7]

Failures in many machine and structures are owing to fatigue. In general, fatigue cracks occur at material flaws. In principle, these inevitable sources of macroscopic stress are not flaws, at least in terms of failure analysis, if properly considered in the design process. However, cavities and voids, non-metallic inclusions, corrosion pit, scratches are additional irregularities and there are numerous instances where failure analysis serves as the root

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cause of component failure [8].

All fatigue cracks begin where the local strain is greatest in the part. This is usually in the notched position. The stress or strain concentration is caused by the several effects of flaws. For example, the site of fatigue cracking of high strength steel is generally a non-metallic inclusion [9]. It is reported that flaws decrease harmfulness when the size decreases below certain limits [10]. In such cases, the properties of other microstructures are responsible for controlling the onset of cracking. In addition, critical length of the flaw is affected by material or ultimate tensile strength, and it is known that the larger the strength, the smaller the size.

When dynamic load is applied as described above, a crack is generated based on various types of defects present in the material, and when a dynamic load greater than a critical load is applied to the crack, the crack grows and finally fracture occurs. As described above, among various types of defects and material shapes, this study aims to study the effect of stress generated according to the location of defects when defects occur at different points of the bending corrugated root. In addition, it is intended to analyze the stress generated in a tensile state or a compressive state.

In general, in the case of a bent tube without wrinkles, the stress of each part can be calculated by a simple theoretical formula. However, in the case of a corrugated bent tube, the stress due to the bending of the entire tube and the stress due to the deformation of each corrugation is superimposed. Therefore, it is difficult to calculate or measure the magnitude of the stress using theoretical equations or experiments, so it is necessary to analyze the stress by an analytical method. There are no research results on the stress around the defects distributed according to the location of each corrugated root. In addition, there is no study on the stress generated according to the bending deflection direction of the corrugated bent pipe. Therefore, in this study, by carrying out studies on such conditions, we attempt to find out the difference in stress according to the variation of the deflection direction and the superposition of stresses occurring in complex shapes.

2. Materials and Methods

The first or second root, which are the position where the maximum stress is generated by bending or torsional deformation, are selected in the bend and corrugated pipe. A defect is present at each of these two points, and the magnitude of the stress generated according to the deformation condition is compared with each other to examine the condition which the maximum stress occurs. The stress generated in the corrugated pipe is compared using the von-Mises stress. In the corrugated pipe, the maximum damage condition is investigated by comparing the stress under the condition that generates the maximum stress by changing the displacement of the opposite side of the defect in the tensile or compressive direction.

As it is hard to find the stress around the defect by an experimental method or a theoretical method using exact solution, the solution is obtained using an approximate numerical method of F.E.M. code, and it is intended to be used for fatigue damage analysis in the vicinity of major cracks when micro cracks occur later.

Analysis model is as shown in Fig. 2. Micro hole is located on the top at the first or second root from the neck. Table 1 represents material properties and dimensions for the model used in the study. Bellows is modeled using the F.E.M. code. Eight node shell elements and elastic - plastic analysis is performed. The diameter of the micro hole is 0.05 mm.

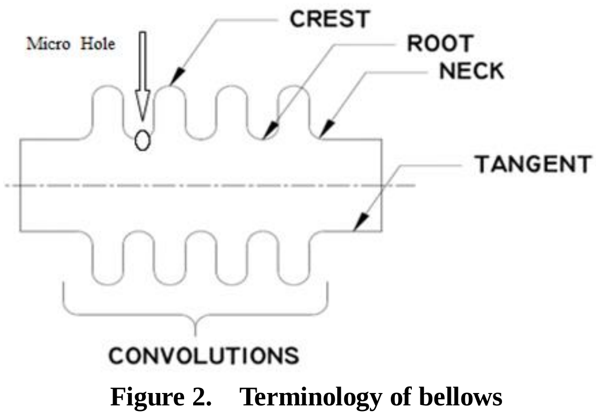


Figure 2. Terminology of bellows

Table 1: Material properties and dimensions

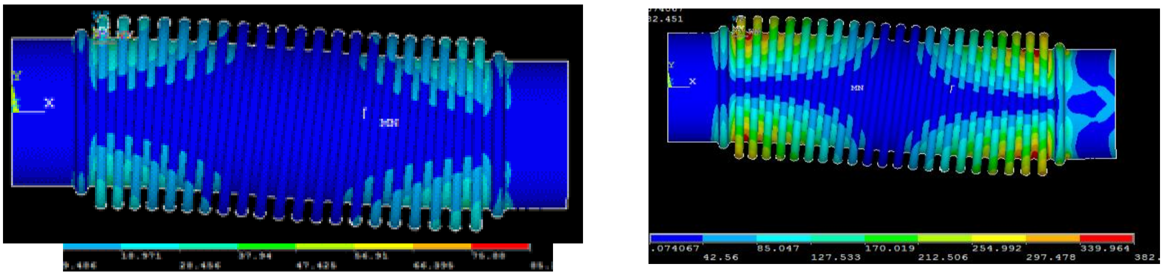
Young's Modulus [GPa]	Inner Diameter of Tube[mm]	Diameter of Micro Hole(mm)	Quantities of Flexible tube [ea]	Thickness [mm]
188	64.32	0.05	23	0.315

3. Result discussions

Figure 3 (a)-(d) shows the stress distribution when the first or second root has a defect and the deflection is 1mm and the rotation angle is 0 degree, or the deflection is 11mm and the rotation angle is 0.01 degree. The stress increases, according to the amount of deflection and the rotation angle increases, regardless of the location of the defect. In the condition that the deflection amount is 1mm and the rotation angle is 0 degree, if there is a defect in the second root, the maximum stress is greater than the case where the first root is defective. However, when the rotation angle is 0.01 degree and the amount of deflection is 11 mm, the stress is greater on the 1^{st} root with a defect. Figure 3(e) shows the stress distribution on the upper side when the second root is defective and the amount of deflection is 11mm and the twist angle is 0.01 deg. From the Figure 3(e), it can be seen that the stress of the left part with defects is greater than that of the right part without defects.

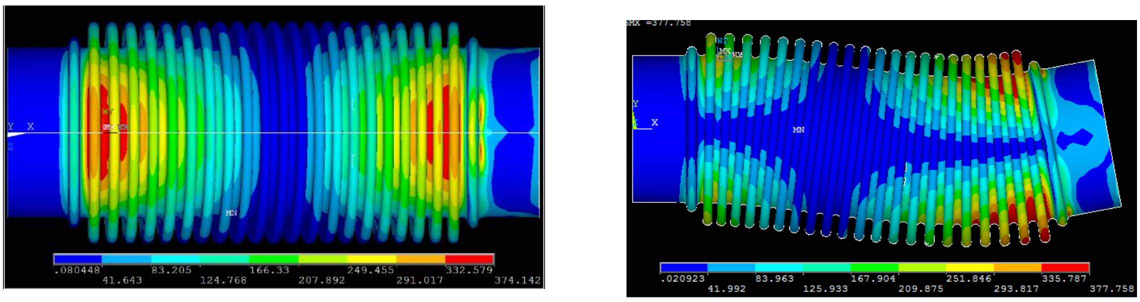
Figure 4 shows the stress distribution when there is a defect in the upper left area and the right side of pipe deflects upward or downward. Based on the defect, the sign is denoted by the minus sign when the deflection is facing downward, and the + sign is used if the deflection is facing upward. The state of stress along the direction of such deflection is calculated.

Figure 5(a) shows the stress change when the bending angle changes from 0 degree to 0.07 degree in the case where the first root is defective. As shown in Figure 4, the + and - signs indicate that the defective area is bent so that it is compressed (+) or tensioned (-). If the bending direction is -, the stress increases with increasing angle. If it bends in the + direction, stress increases as amount of deflection is small and the bending angle is large, but when the amount of deflection is large and the bending angle is large, the stress decreases. In addition, in any case, the magnitude of the yield stress is almost constant regardless of the amount of deflection and the bending angle. Figure 5(b) shows the stress when the second root is defective. If there is a defect in the 1st root, the difference in stress depends on the tension or compression direction. However, if there is a defect in the second root, the stress is similar regardless of the bending direction. In addition, the smaller the bending angle, the greater the overall stress. After yield stress, if the second goal is defective, the stress is increased more than the first goal is defective.



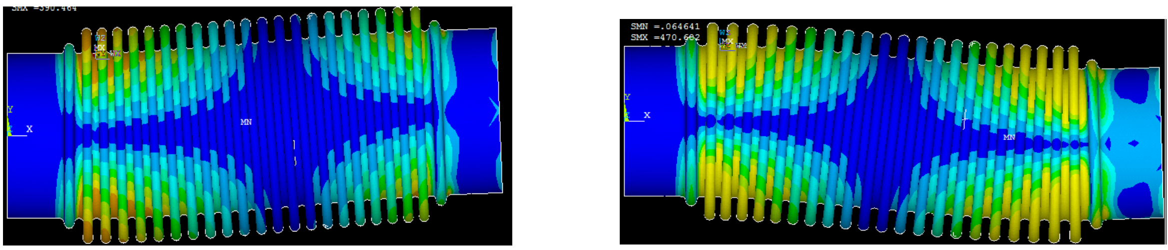
(a)1st root, 1mm, 0 deg-82MPa **(b) 1st root, 11mm, 0.01 deg-378MPa**

(c) 2nd root, 1mm, 0 deg-93MPa **(d) 2nd root, 11mm, 0.01 deg-367MPa(flank)**



(e) 2nd root, 11mm, 0.01 deg-367MPa(upper side)

Figure 3. Stress distribution for the analysis model



(a) Compressive Direction (+) **(b) Tensile Direction (-)**

Figure 4. Bending direction based on the defect

K_{max} for defects in the first or second roots is as shown in Figure 6. Figure 6(a) shows the case where the first root is defective. When the bending angle is 0 deg., K is mostly near 1 and the change in the value according to the amount of deflection is not significantly different. However, when the bending angle is 0.01 deg. and the deflection is 1 mm, K becomes maximum. When the deflection amount is gradually increased, K_{max} changes with bending angle, and K_{max} gradually decreases. K_{max} converges to 1 as the amount of deflection increases. When the amount of deflection is increased, the stress generated in the material without defects is large, so the effect of stress concentration due to defects is small. The magnitude of K_{max} when second root is defective is slightly similar to the case where the first root is defective, although the magnitude is slightly different as shown in Figure 6(b).

K_{max} for defects at 1st or 2nd roots are as shown in Figure 7. When second root is defective, K_{max} is slightly larger than that of the first root, and the distribution pattern is similar in both cases

(a) Defect in 1st root **(b) Defect in 2nd root**

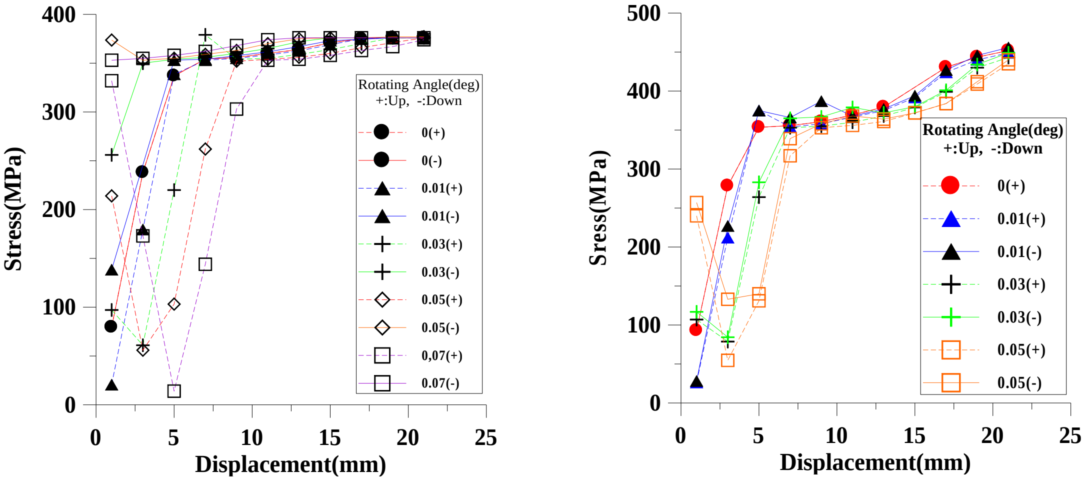
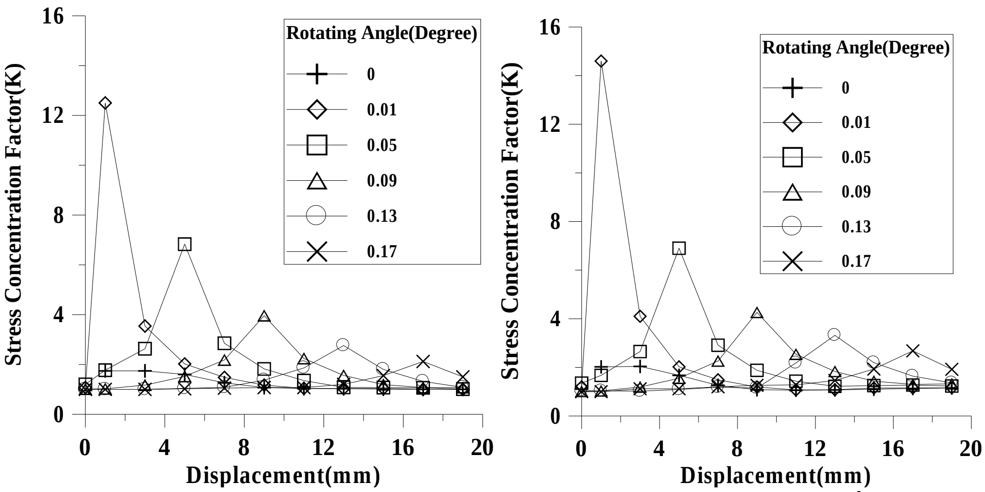


Figure 5. Maximum stress according to displacement and rotation



(a) Defect in 1st root **(b) Defect in 2nd root**

Figure 6. Maximum stress concentration factor with displacement

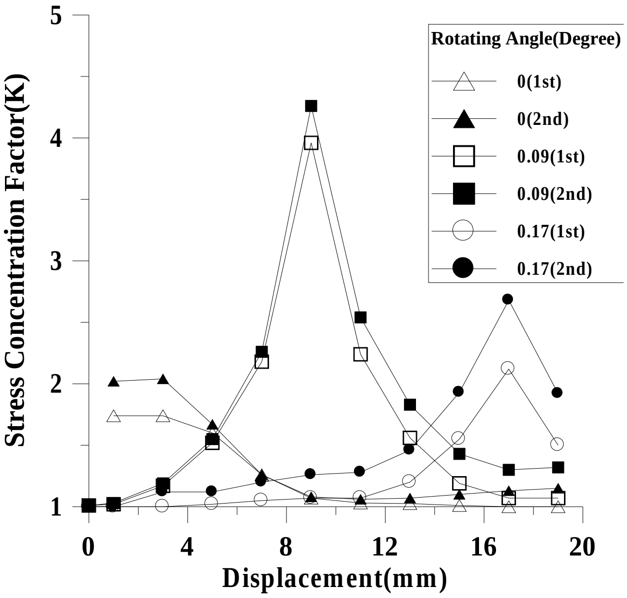


Figure 7. Comparison of stress concentration factors when the first and second root is Defective

4. Conclusions

As results of comparing the stress magnitude, according to the location of the defective root, it can be seen that K_{max}, which occurs when the second goal is defective, is greater than K_{max}, which occurs when the first goal is defective. In addition, the distribution pattern of K_{max} according to deflection magnitude and the torsion angle is found to be similar in both cases. When the deflection condition creates tensile or compressive stress based on the location of the defect, the difference in stress increases depending on the tensile or compressive direction if there is a defect in the first root. However, when the second root is defective, the stress is similar regardless of the bending direction. The smaller the bending angle, the greater the overall stress, and when yielding occurs, the stress in the case of the defect in the second root increases more than the stress of the defect in the first root.

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