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EFFECT OF THE DIFFERENTIAL PRESSURE BY THE BLOW-BY GAS FLOW ON THE PCV VALVE WITH A CRACK

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ABSTRACT−Recently, atmospheric contaminations has become worse due to the increased number of automobile. The PCV (Positive Crankcase Ventilation) valve acts as a flow control to allow re-combustion of blow-by gas by having it flow from a crankcase to an inlet manifold suction tube. Also, during the fabrication of the PCV valve, micro cracks may occur in the valve body and be extended under operation. The excessive stress distribution and crack initiation on the PCV valve body would bring an unstable blow-by gas flow rate control and would cause valve failure. The purpose of this study is to examine the crack affects on the stress and strain variations on the PCV valve according to the inlet and outlet manifold under differential pressures. From the results, we can explain the behavior of the crack extension for a safe condition of PCV valve.

KEY WORDS : PCV valve, Blow-by gas, Crack extension, Finite element analysis, Differential pressure, Stress and strain variation, Stress intensity factor

1. INTRODUCTION

During the past decade, the improvement of the scientific techniques and productivity of automobiles have been astonishing. Nevertheless, environmental pollution, especially atmospheric contamination, has increased as a result of the increase of car production. For these reasons, many car manufacturers have attempted to develop components for the reduction of atmospheric pollution (Hoekstra *et al.*, 1995).

The PCV (Positive Crankcase Ventilation) valve acts as a flow control valve to get a re-combustion of blow-by gas by having it flow from a crankcase to an inlet manifold suction tube. Blow-by gas mostly consist of HC, CO and leads to atmospheric contamination as well as a lowering of engine efficiency (Dhariwal, 1997). However, during the fabrication and working of the PCV valve, some cracks may occur and these cracks may lead to valve failure and an inconsistency of the blow-by gas flow.

The purpose of this paper is to numerically analyze the stress and strain variations of crack initiation and extention in the PCV valve internal area according to the inlet and outlet manifold differential pressure which the blow-by gas flow generates.

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2. NUMERICAL ANALYSIS

2.1. Materials and Mechanical Properties

A commercial X3-PCV valve model (L. Precision Co., Ltd.) was used to evaluate stress and strain states of the inner wall and the behavior of the crack in a valve body. The X3 PCV valve model consists of a main body, spool, flow control spring and cushioning spring. Figure 1 shows the cross section of X3 model.

The region of analysis was limited to the main body of the valve. The main body of X3 PCV valve consists of

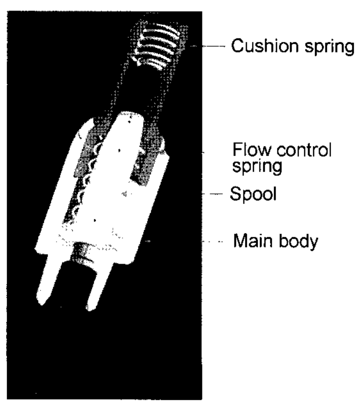


Figure 1. The geometry of the cross section of an X3 PCV model.

Table 1. Mechanical properties of BsBM and SUM22 materials.

Material	Young's modulus (GPa)	Poisson's ratio	Yield strength (MPa)
BsBm	117	0.35	215.6
SUM22	200	0.3	539

the material of BsBM for the inlet and SUM22 for the main body and outlet. It assumed linear elastic behavior. Table 1 shows the mechanical properties of materials.

2.2. Analysis Crack Model Definition

In substance, the spool is operated dynamically by the differential pressure of inlet and outlet of the valve. However, in this study, it is assumed that the blow-by gas flow by the spool displacement changing with the time is in a quasi-stable state.

Figure 2 shows the definition of the spool displacement and differential pressure. The differential pressures resulted from flow analysis (Lee, 2004) of a spool displacement for 1 to 8mm were applied as loads.

Figure 3 shows the finite element model for the PCV valve with a crack. Half of the entire valve model was

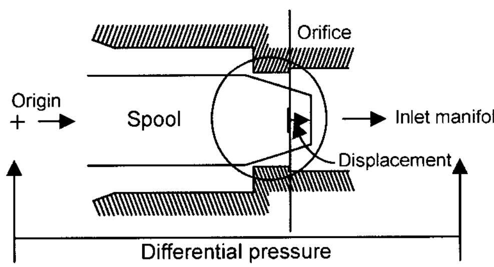


Figure 2. The definition of the spool displacement and differential pressure of X3 PCV model.

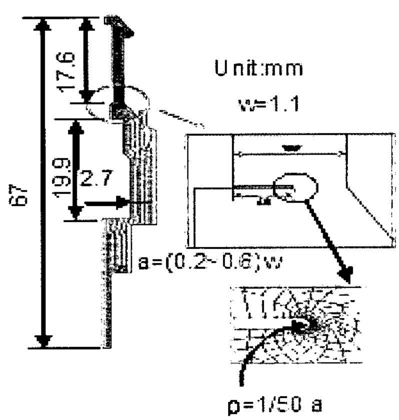


Figure 3. The mesh generation of 2-D finite element model.

considered for FEA with an axis symmetry boundary condition. The evaluation model assumed that a crack may be initiated from the critical point of the internal area which causes maximum stress in the PCV valve model without a crack.

In Figure 3, W means the thickness of the PCV valve in the internal area and the length represents initial crack length. Also ρ means the radius of the notch crack tip. The radius of the tip is limited to 1/50 for the crack length to serve the convenience of evaluation. The number of elements of the PCV valve crack model were from 1628 to 1784 according to the crack size. The number of nodes were from 1400 to 1513 respectively according to the crack size. A finite element model was described using a 2-D quadratic four-node element (ANSYS Manual, 2003). A finite element analysis was conducted by using ANSYS program for 6 cases of differential pressure (50, 100, 200, 300, 400 and 500 mmHg), 4 cases of spool displacement (1, 2, 6 and 8 mm) and 3 cases crack ratio (0.2, 0.4 and 0.6). The crack ratio means a/W.

2.3. Stress Intensity Factor

The stress intensity factor criterion, K, is widely accepted to determine the integrity and failure condition in many industrial applications. It is used to more accurately predict the stress state (stress intensity) near the tip of a crack caused by a remote load or residual stresses (Anderson, 1995). When this stress state becomes critical, crack grows and the material fails. The stress field σ_{ij} on a crack tip in an isotrophic linear elastic material can be written by K_I which is the stress intensity factor for Mode I. Mode I means opening or tensile mode where the crack surfaces move directly apart. Here, we used an alternative equation (Creager, 1966) instead of the equation used for a sharp crack tip because the crack model is considered as the blunted notch crack with a radius ρ.

$$\sigma_{ij}=\frac{K_I}{\sqrt{2\pi r}}f_{ij}(\theta,\rho) \tag{1}$$

Where the coordinates r, θ, ρ are defined as distance from the tip, angle and radius of the blunted crack tip. The correct factor value $f_{ij}(\theta, \rho)$ at an arbitary position is represented as equation (2).

$$f_{ij}(\theta,\rho)=\cos\frac{\theta}{2}\left[1\mu\sin\frac{\theta}{2}\sin\frac{3}{2}\theta\right]\mu\frac{\rho}{2r}\cos\frac{3}{2}\theta \tag{2}$$

The failure criterion described with the fracture toughness is simply represented by the state that fracture will occur when the stress intensity factor, K, becomes equal to or greater than the material's properity, K_{IC} as following equation (3).

$$K\geq K_{IC} \tag{3}$$

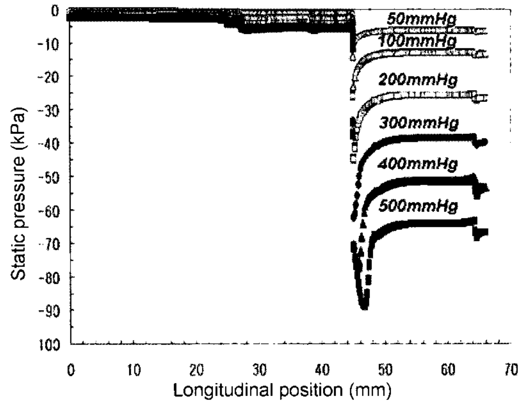


Figure 4. The pressure distribution on the inner valve wall at a spool displacement 2 mm (Lee *et al.*, 2005).

2.4. The Pressure Distribution as Load Effects

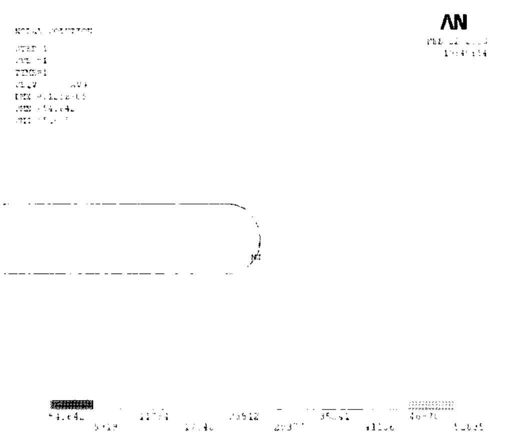
The gas flow in the PCV valve occurres by a differential pressure of inlet and outlet. Therefore the spool in the PCV valve moves according to the relation of fluid force and spring elastic force. In present stress analysis, the pressure distributions in the inner wall body are applied as distribution loads. We got the pressure distribution value from the our previous study (Lee *et al.*, 2005).

Figure 4 shows the example of pressure distributions on the inner valve wall at a spool displacement of 2 mm by the flow characteristic analysis. Here the longitudinal position means the direction in the inner wall from the origin point to the inlet manifold as shown in Figure 2.

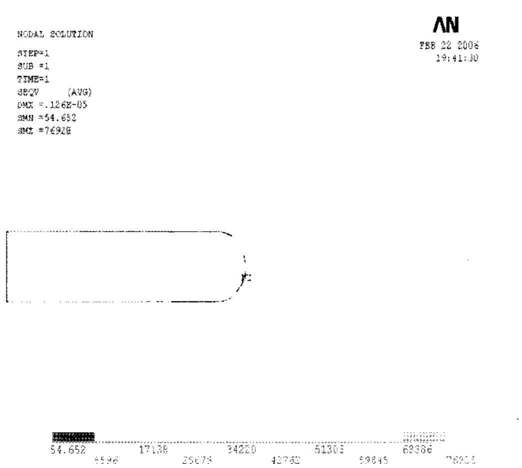
3. RESULTS AND DISCUSSION

Using the X3 PCV valve model, the stress state of the inner wall and the behavior of cracks in the valve body were evaluated numerically. Finite element analysis was conducted to 6 cases of differential pressure, 4 cases of spool displacement and 3 cases of crack ratio.

Figure 5 shows the equivalent von Mises stress contours at the notch crack-tip in the valve main body for the

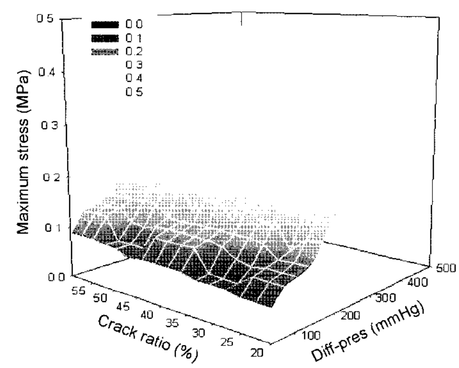


(a) Crack ratio=0.2

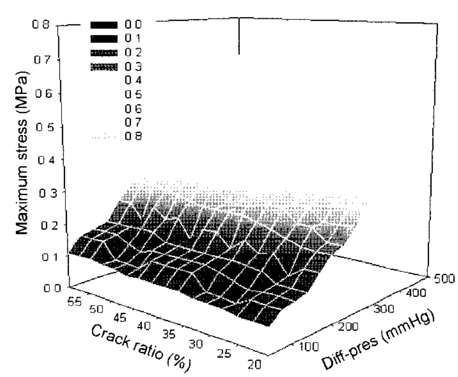


(b) Crack ratio=0.6

Figure 5. The equivalent von Mises stress contour at the notch crack-tip (pressure 50 mmHg, spool displacement 8mm, crack ratio 0.2 and 0.6).



(a) Spool displacement-1mm



(b) Spool displacement-8mm

Figure 6. The variation of the maximum equivalent stresses at the round crack-tip according to the crack ratio and differential pressure (spool displacement 1,8 mm, different crack ratio 20, 40, 60%).

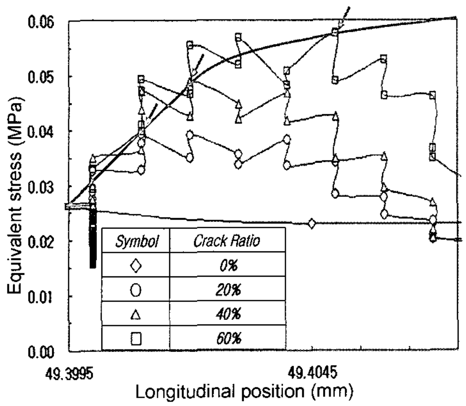


Figure 7. The variation of the equivalent stresses at the round crack-tip according to the crack ratio (0, 20, 40, 60%).

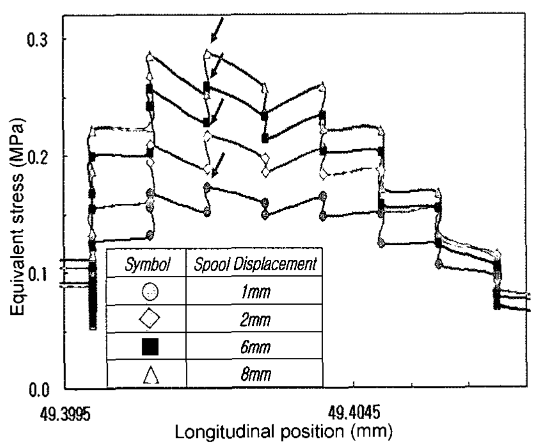


Figure 8. The variation of the equivalent stresses at the round crack-tip according to the spool displacement (1, 2, 6, 8 mm).

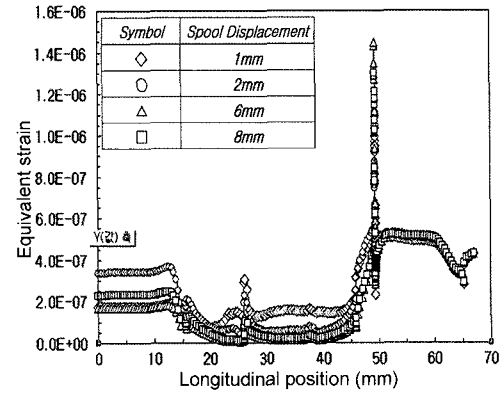


Figure 9. The variation of the equivalent strain on the inner wall of the valve body according to the spool displacement (1, 2, 6, 8 mm).

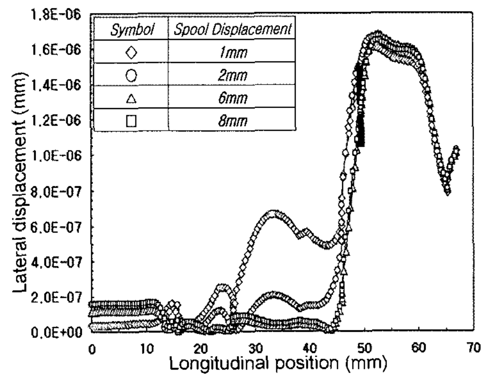


Figure 10. The variation of the lateral displacement along the valve inner wall according to the spool displacement (1, 2, 6, 8 mm).

crack ratio of 0.2 and 0.6, the differential pressure 50 mmHg and the spool displacement 8 mm. The maximum stress of all cases occurred in a round crack-tip and the case of crack ratio of 0.6 is slightly higher than the case of the crack ratio of 0.2.

Figure 6 shows the variations of the maximum stress at the crack-tip according to the crack ratio of 0.2, 0.4 and 0.6 for the spool displacement (1 and 8 mm) and the differential pressure (50~500 mmHg).

In the spool displacement of 8 mm case of Figure 6(b), results obtained had the same differential pressure (50 mmHg) and spool similarly. However the maximum stress values increased rapidly according to the increase of the differential pressure and showed about 40% higher for given spool displacement variation.

For the displacement (1 mm), the position of maximum stress according to the variation of crack ratio (0, 0.2, 0.4 and 0.6) were shown in Figure 7. In the case of the same spool displacement (1 mm) and differential pressure (50 mmHg), the positions and values of the maximum stress increased with higher value as the crack ratio increased.

In the case of same crack ratio 0.4 for the same 200 mmHg differential pressure, the position of maximum stress of each spool displacement was shown in Figure 8.

The maximum stress occurred in the same position for each spool displacement. Those of the other differential pressure are similar to the case of the same differential pressure. The maximum stress increased with higher value according to increasing differential pressure. However, the longitudinal positions of maximum stress values are independent of the spool displacement. In Figures 7 and 8, the left index equivalent stress means equivalent von Mises stresses.

Figure 9 shows the variation of equivalent strain on the inner wall of the valve body according to a change of spool displacement for the same differential pressure. The equivalent strain corresponds to the equivqlent von Mises

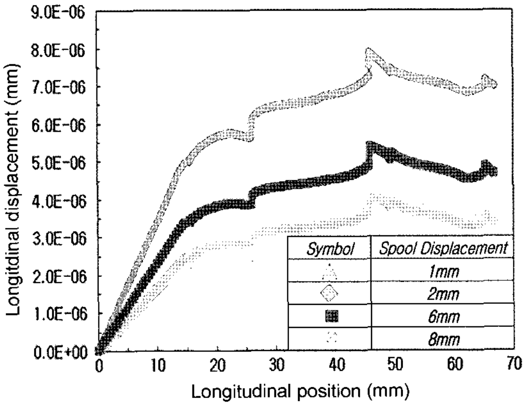


Figure 11. The variation of the longitudinal displacement along the valve inner wall according to the spool displacement (1, 2, 6, 8 mm).

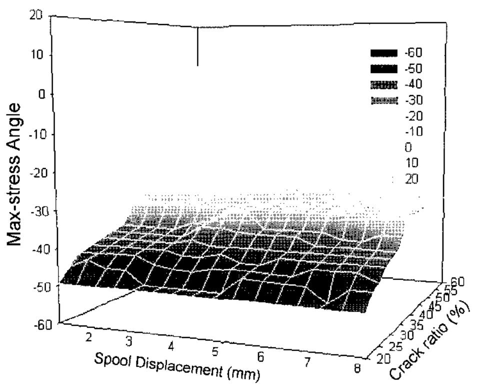


Figure 12. The maximum stress angle at the round crack-tip according to the crack ratio and spool displacement (1, 2, 6, 8 mm).

stress. The variations of equivalent strain are analogous to each case of spool displacement from inlet to outlet. And the maximum values of all the cases occurred in the round crack-tip. Yet, equivalent strains are independent of the spool displacement.

Figure 10 shows the variation of the lateral displacement according to the change of the spool displacement for the same differential pressure. The variations of lateral displacement of the round crack-tip region and orifice region are independent of the spool displacement. In the case of spool displacement of 2 mm, it has the largest value, compared with other spool displacements, because the flow can be increased when the spool displacement is 2 mm.

Figure 11 shows the variation of the longitudinal displacement according to a change of the spool displacement for the same differential pressure (200 mmHg) and crack ratio (0.4). The maximum stress occurred in the same position (45.9 mm) for each spool displacement.

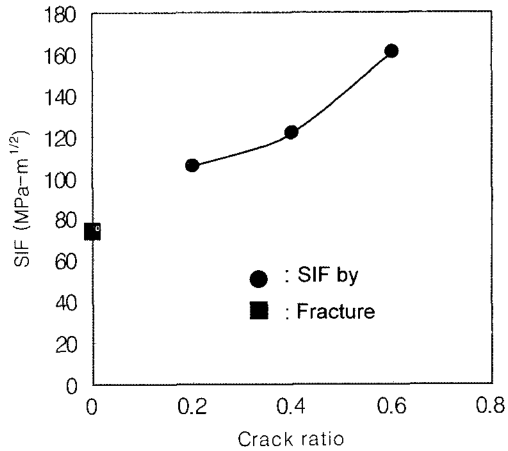


Figure 13. The variations of stress intensity factor according to the crack ratio.

The variations of longitudinal displacement have linearly changed from the inlet to a position of 14 mm, and then, it has passed the inflection point at a position of 26 mm and has increased to the orifice region. These trends are independent of the change of spool displacement and differential pressure.

The angles obtained from the position of the maximum stress at the round crack-tip according to the changes of crack ratio and spool displacement are shown in Figure 12.

The maximum stress angles represent the possible direction of the crack extension. The direction of the crack extension using the maximum stress position changes from downward to upward according to the increasing of crack ratio. A more detailed study for the crack extension will be conducted next time.

Figure 13 shows the variations of stress intensity factors according to the crack ratio in case of displacement of 2 mm, and a differential pressure of 100 mmHg. In this study, fracture toughness, K_{IC}, was obtained by using a simple equation (4) from a mechanical properties (Asami *et al.*, 1994).

$$K_{IC}=0.061\sqrt{\frac{E\delta(\sigma_B+\sigma_y)}{1-\nu^2}}-47.4 \tag{4}$$

Here E, δ, σ_B, σ_y and ν means Young's modulus 200 GPa, fracture elongation 4%, fracture strength 230 MPa, yield strength 220 MPa and Poisson ratio 0.3, respectively. (ASM, 1990) Using equation (4) we have a fracture toughness K_{IC}=73.91 MPa-m$^{1/2}$ in the orifice area material. The material of the orifice area is SUM22. In Figure 13, stress intensity factor according to crack ratio extension is higher from 1.43 to 2.17 times than fracture toughness. This means that the crack initiation and extension beyond 20% for thickness is critical in the PCV valve.

4. CONCLUSION

Finite element analysis of the influence of in-outlet differential pressure for X3 PCV valve that affects failure of the automobile crankcase and decrement of auto exhausts carried out using the ANSYS code. X3 PCV valve model was used to evaluate the stress state of the inner wall and the behavior of cracks in a valve body. Conclusions are as followed.

Longitudinal displacement is somewhat as large as a lateral displacement. Maximum stress and strain gradually increased with higher values according to increasing differential pressure and crack ratio, but those of stress and strain are independent of the spool displacement. Maximum stress position angle in the crack-tip was affected by crack ratio rather than spool displacement.

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REFERENCES

Anderson, T. L. (1995). *Fracture Mechanics*. CRC. Florida.

ANSYS User's Manual **III** (2005).

Asami, K., Sugiyama, Y. and Nakayama, S. (1994). A simple evaluation method of fracture toughness of metals by using tensile properties. *JSME, Materials and Mechanics Div.*, **A**, 940–37, 174–176.

ASM Internationals (1990). *Metals Handbook*, **1**, *Properties and Selection*. Materials Park. Ohio.

Cheng, N. Y. and Park, S. I. (2004). Detection of interfacial crack length by using ultrasonic attenuation coefficients on adhesively bonded jonits. *Int. J. Automotive Technology* **5**, **4**, 303–309.

Creager, M. (1966). *Stress Corrosion Models and Some Associated Boundary Value Problems*. M. S. Thesis. Lehigh University. 37.

Dhariwal, H. C. (1997). Control of blowby emissions and lubricating oil consumption in I.C. Energys. *Energy Convers. Mgmt*, **38**, 10–13, 1267–1274.

Hoekstra, R. L., Ollier, K., Mulligan, N. and Chew, L. (1995). Experimental study of a clean burning vehicle fuel. *Int. J. Hydrogen Energy* **20, 9**, 737–745.

Lee, J. H., Choi, Y. H. and Lee, Y. W. (2005). Computational analysis of flow characteristics of a PCV valve. *Trans. Korean Society of Automotive Engineers* **13, 4**, 66–73.

Lee, Y. W. (2004). A study on flow characteristics of PCV valve. *Proc. ISAME*, 171–176.

Shudo, T., Nagano, T. and Kobayashi, M. (2003). Combution characteristics of waste pyrolysis gases in an internal combustion engine. *Int. J. Automotive Technology* **4**, **1**, 1–8.