Proceedings of the 3rd International Conference on
Fracture Fatigue and Wear, pp. 201-206, 2014

ROLLING CONTACT FATIGUE SIMULATION USED FOR FULL-OPEN TYPE GREENHOUSE

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Abstract: The green house is often used to add the quality and value of agricultural products. Newly developed full open type green house has a lot of attracted attention whose roof opens and closes automatically in order to control the temperature. However, since the roof opens and closes very often, the cover sheet can be used only for 3-4months. This is because the plastic film is damaged between the support pipe and rolling pipe during opening-closing affected by fatigue and wear. In this study, the damage mechanism is investigated for the several plastic films used for the full open type green house. In the first place, FEM analysis is performed to evaluate the damage of plastic film between pipes under different film materials. Here, the maximum contact pressure and thickness reduction are analysed under static contact analysis and rolling contact analysis as the most important factors. Finally, rolling fatigue experiment is performed to investigate the damage with changing plastic films. Then, the results are compared with the FEM analysis.

Keywords: contact problem; finite element method; polymer materials

1 INTRODUCTION

The new full-open type greenhouse is a building in which plants are grown at all season. It is a structure consisting of plastic roof and walls as shown in Fig. 1. To control room temperature, the plastic roof open and close frequently and automatically, which leads to the tear of the roof in short periods. In this study, FEM analysis is performed to evaluate the damage of plastic film between pipes under different film materials. Here, thickness reduction is analyzed under static contact analysis and rolling contact analysis as the most important factor. Moreover, rolling fatigue experiment has been done to simulate the real damage in plastic film and investigate the effect with changing plastic films.

2 OBSERVATION ON DAMAGED PLASTIC FILM

To find the out the possible reasons that cause the fracture, we observed several pieces of damaged plastic film by using optical microscope and scanning electron microscope. Figure 2 (a) shows the surface tear of damaged piece. We found that due to the rolling squeezing between two pipes, plastic film extends and that some creases cause on it. Figure 2 (b) shows a line scar on the flaky surface, which is caused by the cycle action of friction and pressure between pipe and plastic film or between plastic films.

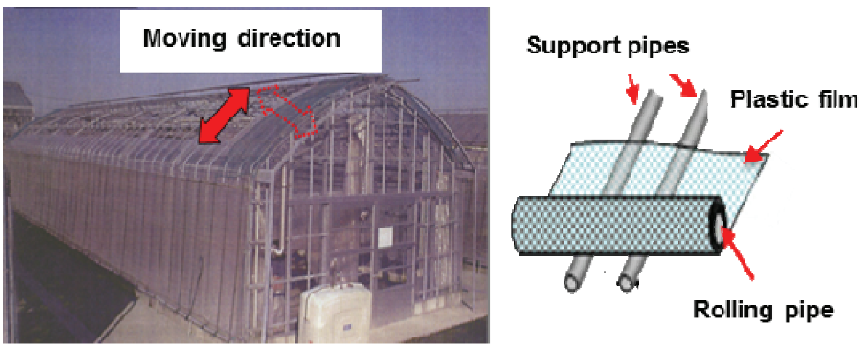
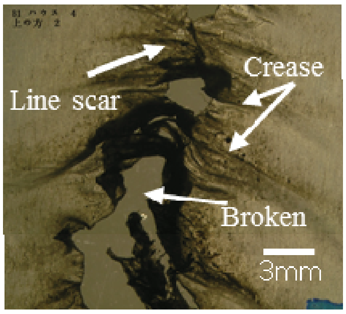
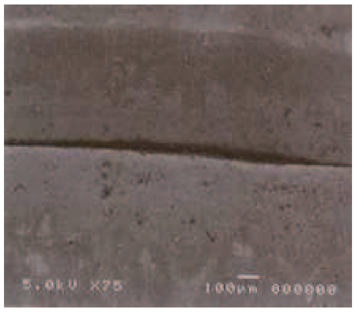


Fig. 1 Full-open greenhouse

[1]


(a) Surface tear

[2]


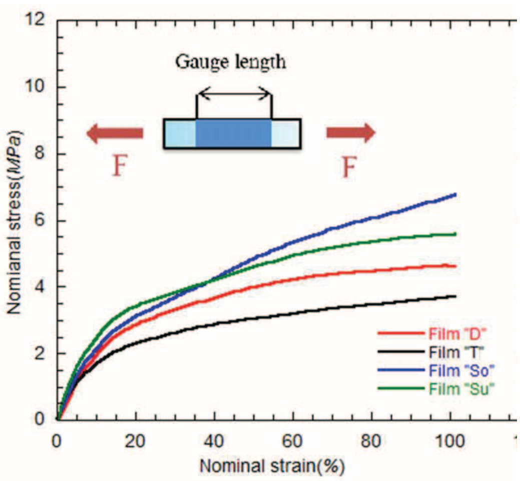
(b)Line scar

Fig. 2 Damaged plastic film

3 FEM MODEL AND RESULTS FOR STATIC CONTACT ANALYSIS

Figure 3 (a) shows the stress-strain diagram of plastic film which is used for FEM analysis. Because polymer material strength decreases with increasing the temperature [1], the ambient temperature for tensile test is assumed to be 70°C which equals to the highest temperature on pipes of greenhouse in summer. The product names of plastic film used for greenhouse are called “T”, “D”, “So”, “Su” for short.

FEM mesh for standard model is shown as Fig. 3(b), which is used to evaluate the contact pressure and thickness reduction of plastic film between pipes. The dimension of the model is consistent with the actual dimension on full-open greenhouse. Both support pipe and rolling pipe have the same diameter $d_1=d_2=38$mm, and thickness of plastic film is 0.15mm. The number of elements is 1.5×10^5 and the smallest element size is 0.1mm×0.1mm×0.375mm which may provide high accuracy without large calculation time. The friction coefficient between pipe and plastic film is assumed as 0.15 [2], and the load is 75N. It is known that each support pipe may carry 15N on average, however due to the manufacturing error we assume the largest load may be 75N.

[3]


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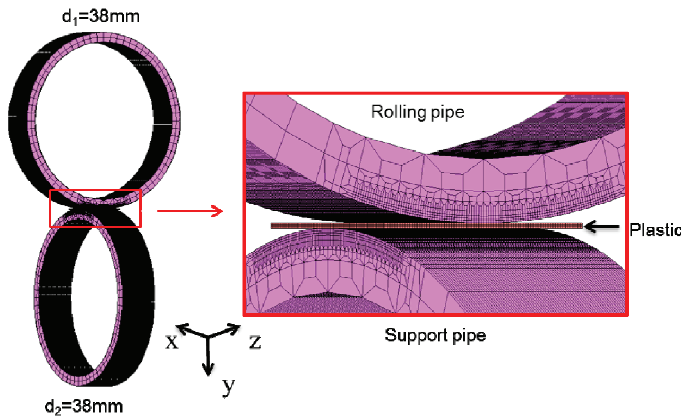
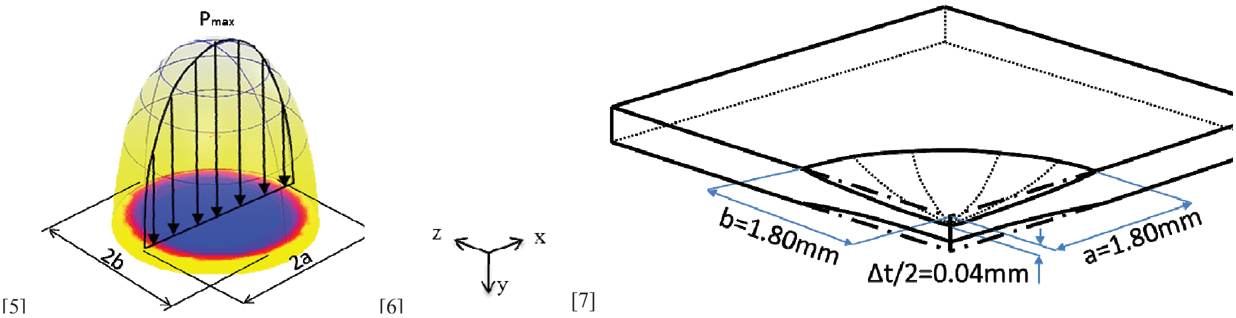


(a) S-S diagram at temperature 70°C (b) FEM mesh for standard model under static contact analysis

Fig. 3 FEM mesh for standard model and S-S diagram of different material

Various contact stresses are investigated in Ref. [3], However there is no results available for the plastic film between the two pipes. Figure 4(a) shows profiles for stress along the y-axis for plastic film D and the maximum stress along the y-axis p_{max}=17.54 MPa appears at the centre of plastic film. Figure 4(b) shows profile of thickness reduction under stress distribution of Figure 4(a). According to the results, the maximum thickness reduction appears at the centre of the plastic film ($\Delta t/2$=0.04 mm) and the reduction of the upper and lower surface is the same.



(a) Profiles for stress σ_y (b) Profile of Thickness reduction (quarter model)

Fig. 4 Profiles of stress and thickness reduction for plastic film “D”.

Table 1 shows the thickness reduction and maximum contact pressure of four kinds of materials. According to the results, the maximum contact pressure of plastic film “So” is the largest, and thickness reduction of plastic film “T” is the largest among four kind of materials.

Table 1 Results for different materials

Plastic film	Film “T”	Film “D”	Film “So”	Film “Su”
p_{max}[MPa]	16.0	17.5	19.5	18.0
Contact area[mm^2]	11.1	10.2	8.87	8.7
Maximum thickness reduction Δt_{static} [mm]	0.090	0.080	0.074	0.072

4 FEM MODEL AND RESULTS FOR ROLLING CONTACT ANALYSIS

Static contact analysis was performed, and the maximum contact pressure and thickness reduction between pipes was discussed. However, in fact the rolling pipe rolls up the plastic film as a rolling action in full-open greenhouse. It is necessary to investigate the effect of rolling action compared with the static analysis. FEM mesh for standard model is shown as Fig.5, which is used for rolling contact analysis. Both support pipe and rolling pipe have the same diameter d_1=d_2=38mm for the perpendicular contact model. The number of elements is 6.2×10^4 and the smallest element size is 0.09 mm X 0.09 mm X 0.375 mm which may provide high accuracy without large calculation time. Because Young's modulus of iron is much larger than the plastic film (about 420 times), in order to simplify the model, the models of pipes are regarded as rigid models for rolling contact analysis. The rolling speed for rolling pipe is 8.38rad/min and rolling time is 1.3s in FEM simulation. The load is 75N which is the same as the one of static contact analysis.

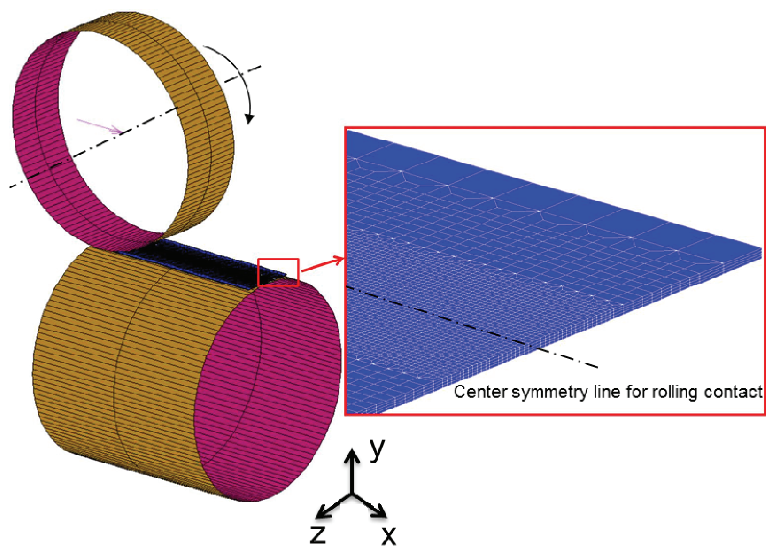


Fig. 5 FEM mesh for standard model under rolling contact analysis.

Figure 6 shows the thickness reduction Δt of y-direction on the plastic film. According to Figure 7, the red line shows the contact result of the static contact analysis and the blue line shows the contact result of the rolling contact analysis. The initial thickness of plastic film is t_0=0.15 mm. The notations Δt and t represent thickness reduction and final thickness of plastic film. Moreover, the relation between thickness reduction and final thickness of plastic film is $\Delta t + t = t_0$ =0.15 mm. According to these results, the maximum thickness reduction does not appear at the original point. Table 2 shows the data of thickness reduction on four kinds of material under static contact analysis and rolling contact analysis. According to the result, thickness reduction of plastic film "T" is larger than that of other materials in steady state under rolling contact analysis. The results in thickness reduction in rolling contact analysis are found to be nearly equal or larger than the ones in static contact analysis by 10%.

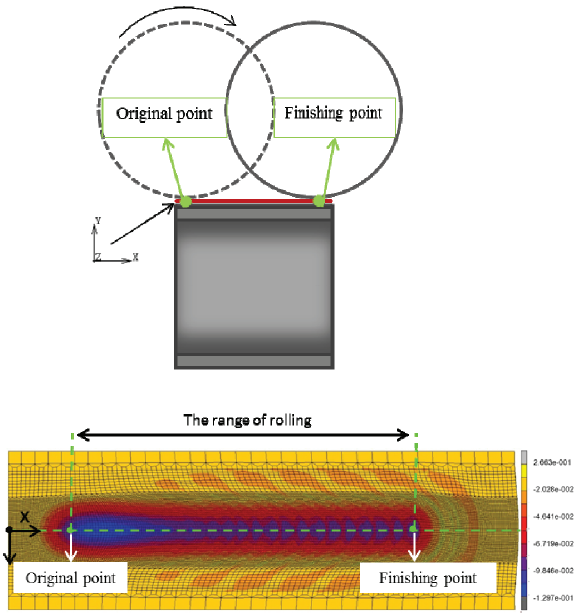


Fig. 6 Typical thickness reduction Δt distribution map

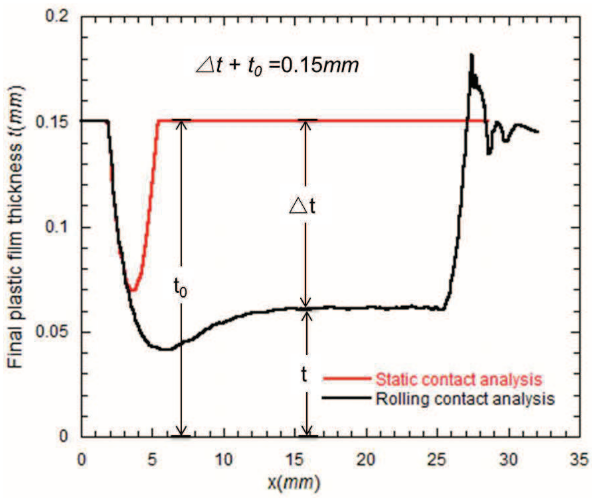


Fig. 7 The final thickness of plastic film in static contact analysis and rolling contact analysis

Table 2 Thickness reduction Δt for static contact analysis and rolling contact analysis

Plastic film	Film "T"	Film "D"	Film "So"	Film "Su"
Maximum thickness reduction Δt_{static} [mm] under static contact analysis	0.0897	0.0804	0.0744	0.0719
Thickness reduction $\Delta t_{rolling}$ [mm] in steady state under rolling contact analysis	0.108	0.0889	0.0708	0.0748
$\Delta t_{rolling} / \Delta t_{static}$	1.20	1.10	0.95	1.04

Figure 8 shows the final elongation of plastic film in x direction for plastic film "T". The original length and elongation are represented by l and Δl. Table 3 shows the data of thickness reduction and elongation under rolling contact analysis. It is found that elongation is increasing when thickness reduction increases. Since the both sides of rolling indentation are constrained, only the central part of the rolling indentation is elongated during rolling, thus the stretched portion at the central film leads to crease. Therefore formation of crease is closely relative to elongation, and crease is considered as the early damage before line scar.

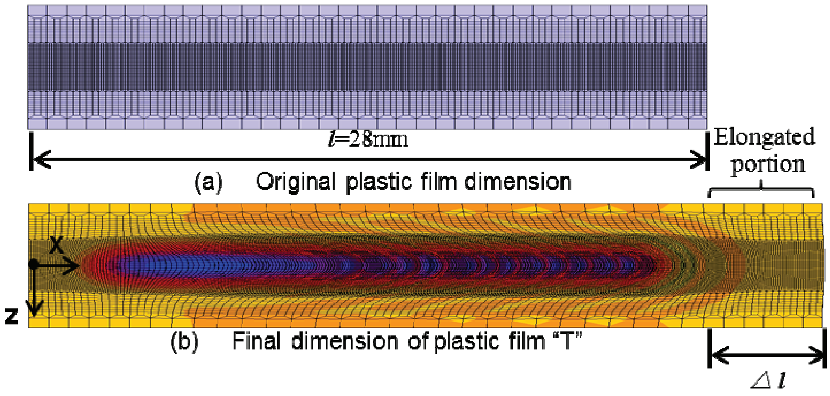


Fig. 8 The final elongation of plastic film in x direction for plastic film "T".

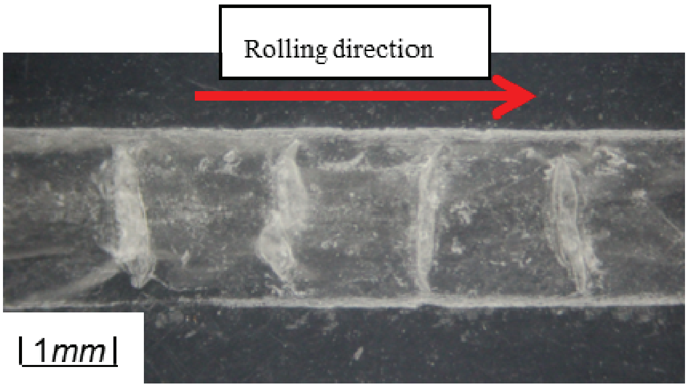
Table 3 The final elongation of plastic film Δl and the thickness reduction Δt for steady state

Plastic film	Film "T"	Film "D"	Film "So"	Film "Su"
Final elongation Δl [mm]	5.12	3.71	2.64	2.83
Thickness reduction $\Delta t_{rolling}$ [mm]	0.109	0.089	0.070	0.075
$\Delta l / l$	0.183	0.133	0.094	0.101
$\Delta t_{rolling} / t_0$	0.727	0.593	0.467	0.500

5 ROLLING CONTACT EXPERIMENT RESULTS

Rolling contact experiment has been done to simulate the real damage in plastic film. The temperature on support pipe is assumed as 70°C which equals to the highest temperature on pipes of greenhouse in summer. The load is 75N which is same as contact analysis. It is known that each support pipe may carry 15 N on average, however due to the manufacturing error we assume the largest load may be 75 N. To control room temperature, the plastic roof open and close 10 times for one day. In order to simulate damage of plastic film which has used for one month, cycles for rolling action are assumed as 300 times. Figure 9 shows damage of test piece which is taken by optical microscope. Four line scars are seen on the Fig. 9. Table 4 shows the results of rolling contact experiment and analysis. According to the results, elongation ratio is related to the reduction ratio under rolling contact analysis. Elongation ratio increases with increasing reduction ratio. Figure 10 shows the relationship between number of line scar n and reduction ratio $\Delta t_{rolling} / t_0$. From the comparison between the results of rolling contact experiment and the results of rolling contact analysis, the number of line scar under rolling contact experiment increases with increasing the reduction ratio under rolling contact analysis.

[8]



[9]

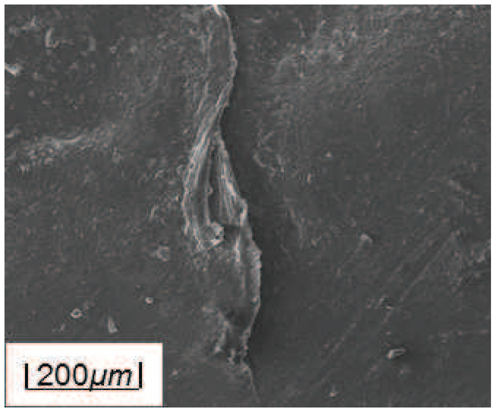


Fig. 9 Microscopic photo of film rolled 300 times at 70℃ (film "D")

Table 4 Number of line scar per centimeter for four kinds of plastic film

Plastic film	Film "T"	Film "D"	Film "So"	Film "Su"
Number of line scar n under rolling contact experiment	3.85	2.95	1.2	0.15
Elongation ratio $\Delta l / l$ under rolling contact analysis	0.183	0.133	0.094	0.101
Reduction ratio $\Delta t_{rolling} / t_0$ under rolling contact analysis	0.727	0.593	0.467	0.500

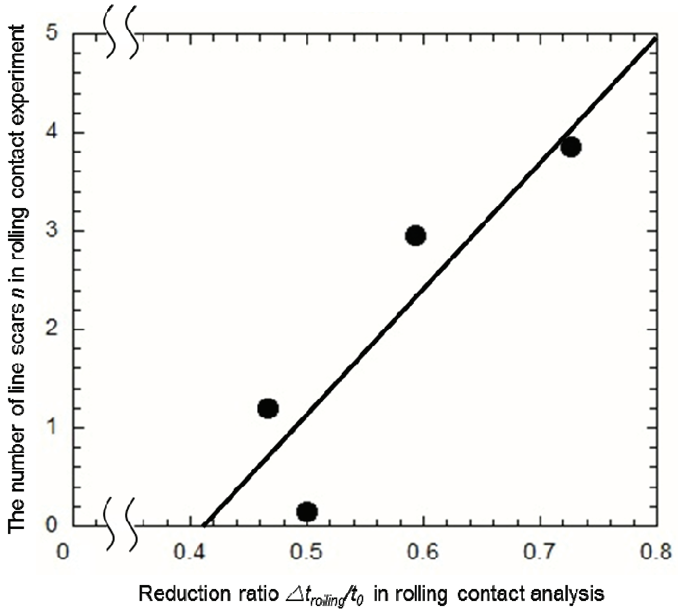


Fig. 10 Relationship between number of line scar n and $\Delta t_{rolling} / t_0$

6 CONCLUSION

In this study, the damage mechanism is investigated for four kinds of plastic films used for the full open type greenhouse. From the FEM analysis and rolling experiment, the following results can be obtained.

1) From the comparison between the results of rolling experiment and the results of rolling contact analysis, the number of line scar in rolling tests increases with increasing the reduction ratio in rolling contact analysis.
2) The results in thickness reduction in rolling contact analysis are found to be nearly equal or larger than the ones in static contact analysis by 10%.
3) According to the results of rolling contact analysis, it is found that elongation is increasing when thickness reduction increases. Since the both sides of rolling indentation are constrained, only the central part of the rolling indentation is elongated during rolling, thus the stretched portion at the central film leads to crease. Therefore formation of crease is closely relative to elongation, and crease is considered as the early damage before line scar.

7 REFERENCES

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