Optimization Scheme for Bending Process of Display Module Based on Simulation

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Abstract

The narrow bezel design is a strong demand for full-screen smartphones, where the width of the bottom bezel is limited by the radius (R0) of the Flexible Printed Circuit (FPC) after bending and the process capability of the FPC bending technology. Reducing the radius (R0) and adjusting the bending process parameters can decrease the size of the bottom border. But small R0 will increase the strain in the bending area, significantly raise the risk of metal cracks. This paper introduces a risk assessment and process optimization scheme of bending process. Based on simulation, optimizing the bending process to reduce the strain of the metal layer. Evaluating the impact of process accuracy. Comparing the differences of bending process between 2D and 3D curve cover glass (CG). Providing optimization directions for the design of deep-curve narrow bezel to reduce the defect rate and reliability risks.

Author Keywords

Display module; 3D CG narrow bezel; bending simulation.

1. Introduction of FPC bending process

FPC bending is a process where the FPC is bent and attached to the back of the panel. The radius (R0) after bending is the main limiting factors affecting the size of the bottom frame. The main process flow includes: adsorbing the FPC with the flipping head, rotating and moving the FPC to the designated position, pressing down with the pressure head to the specified pressure, and then unloading (Figure 1).

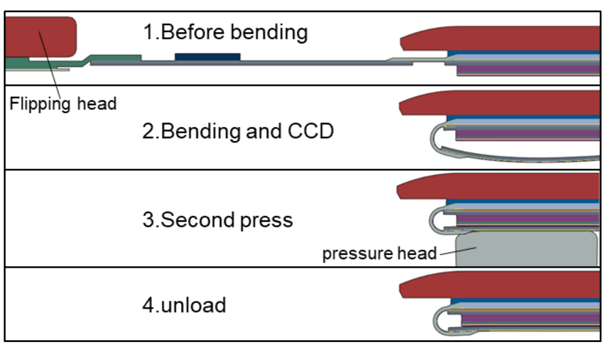

Figure 1. Sketch map of main processes

The common stacking in the bending area is shown in Figure 2. As R0 decreases, the metal layer in the bending area will break when it reaches the tensile strength. The failure phenomenon is shown in Figure 3. Base on simulation, we can obtain the strain distribution of the film layer of interest in the bending area, usually the metal layer, during the entire bending process. In Figure 4, A is the strain peak in the bending area on the FPC side, and B is the strain peak on the panel side, and C is the strain peak of the center of circular arc. Among them, peak A and C occurs during the rotation phase, while peak B occurs during the pressing phase. The red line represents the final strain and the blue line represents the maximum strain throughout the entire process. When the process parameters are not suitable, the strain during the bending process will be much greater than the final state.

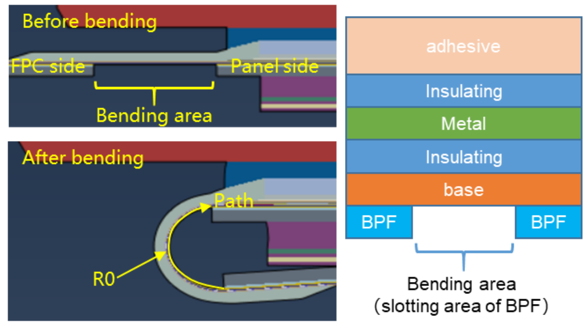

Figure 2. Panel stack of bending area

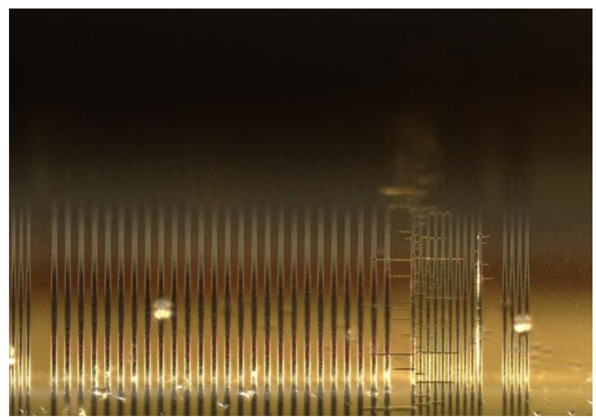

Figure 3. Metal crack of bending area

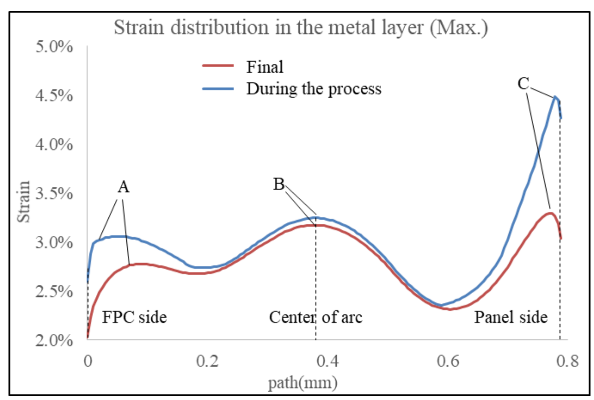

Figure 4. Strain distribution in the bending area

2. The influence of process parameters on the bending area base on simulation

Bending process parameters are categorized into three types: 1. Initial position of the flipping head relative to the display module, 2. Relative position of the pressure head and pressure. 3. Trajectory parameters L/R of the flipping head. Usually, the optimal solution for the L is close to X0 (as shown in Figure 7), and the R is close to the radius R0 (as shown in Figure 2). Different equipment manufacturers have differences trajectory

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logic built-in their equipment. For example, the trajectory of the flipping head movement is shown in Equations 1 and 2. When the bending is completed, the horizontal displacement of the flipping head is X = 2L-πR and the vertical displacement Y=2R.

$$X = L(1 - \cos\theta) + R \times (\theta \times \cos\theta - \sin\theta) \quad (1)$$

$$Y = L \times \sin\theta + R \times (1 - \cos\theta - \theta \times \sin\theta) \quad (2)$$

The simulation result for the trajectory parameters L/R and the initial position correction parameter △Y of the flip head in a 2.5D CG project is shown in Table 1 and Table 2. When the trajectory is not overstretched, the strain at the center of the arc is the largest, whether in the final state or during the process. When the trajectory is overstretched, the strain increases in a certain area from the center of the arc to the edge of panel side (blue line in Figure 4). In addition to the fracture of the metal wire in the bending area, it may also causes the failure of the inorganic layer near the bending area in reliability testing. Some smart phones on the market have already adopted the over-pulling method to reduce the size of the lower bezel. The optimal trajectory selection logic is defined as the strain on the panel side and FPC side is not greater than the center of the arc.

Table 1. The Max. Strain of the center of arc

Max. Strain Center of arc (%)				R					
				0.298	0.318	0.338	0.358	0.378	0.398
ΔY	0	L	9.17	-	-	-	-	3.34	-
			9.21	-	-	-	-	3.43	3.43
	-0.1		9.09	-	-	3.28	-	-	-
			9.13	-	-	3.39	3.31	-	-
			9.17	-	-	3.36	3.38	3.33	-
			9.21	-	-	-	3.30	3.33	3.31
	-0.2		9.09	3.35	3.31	3.25	-	-	-
			9.13	-	3.31	3.30	3.25	-	-
			9.17	-	-	3.27	3.28	3.25	-
			9.21	-	-	-	3.26	3.28	3.26

Table 2. The Max. Strain of panel side

Max. Strain Panel side (%)				R					
				0.298	0.318	0.338	0.358	0.378	0.398
ΔY	0	L	9.17	-	-	-	-	**2.90**	**-**
			9.21	-	-	-	-	**2.86**	**2.87**
	-0.1		9.09	-	-	**2.94**	-	-	-
			9.13	-	-	**2.97**	**2.94**	-	-
			9.17	-	-	3.68	3.45	**3.23**	-
			9.21	-	-	-	4.32	4.05	3.79
	-0.2		9.09	4.84	4.66	4.48	-	-	-
			9.13	-	5.44	5.26	5.08	-	-
			9.17	-	-	6.12	5.85	5.67	-
			9.21	-	-	-	6.80	6.51	6.22

Based on the simulation results presented in Tables 1 and 2, the following conclusions can be drawn: firstly, within a certain debugging range, the trajectory has a minimal impact on the strain of the center of the arc. The difference between the maximum and minimum strains in the simulation group is only about 0.1%. Secondly, the trajectory has a significant impact on the strain of the panel side, and the impact becomes more pronounced as ΔY increases. This indicates that in practical processes, it is necessary to control the initial position accuracy of the flipping head to reduce risks. Finally, the trajectory parameters corresponding to the strains underlined in the table are the recommended debugging ranges base on simulation.

3. The influence of the tolerance of BPF (bottom protective film) based on the optimal trajectory

Tolerance of the width of the BPF slot area (the size of bending area): It is assumed that the BPF slot area has a tolerance of ± 0.05mm and the bonding tolerance is 0. The maximum strain in each bending area are shown in Figure 5. Simulation data shows that the strain difference at the center of arc is small (0.07%), the panel side is small too (0.23%), and the FPC side is large (0.82%). This is related to the way of alignment.

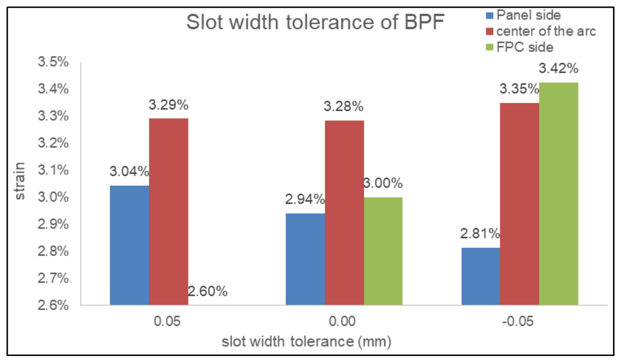

Figure 5. The influence of the tolerance of the slot area

The bonding tolerance of BPF: Using the same approach, assuming a fitting tolerance of ±0.05mm and a slotting tolerance of 0. The maximum strain in each bending area are shown in Figure 6. Simulation data shows that the strain difference on the center of arc is small (0.1%), the panel side is large (1.04%), and the strain difference on the FPC side is large too (0.92%). In practical processes, tightening the bonding accuracy is beneficial for reducing the strain on the panel side and FPC side, with little impact on the center.

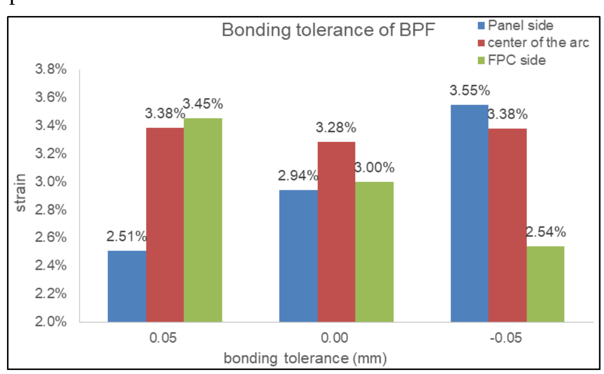

Figure 6. The influence of the bonding tolerance

4. The difference of bending process between 3D and 2D CG

In addition to conventional 2D CG, many smart phones on the market use 3D curved CG. The difference between 3D and 2D CG is shown in Figure 7. The initial state before bending of the 2D CG panel is in horizontal. The distance from the turning center of flipping head to the starting point of the bending area is X0. 3D CG interfering the panel, and making the panel and FPC redundant. X0 is reduced to X1, and the vertical redundancy increase to Y1 from ΔY.

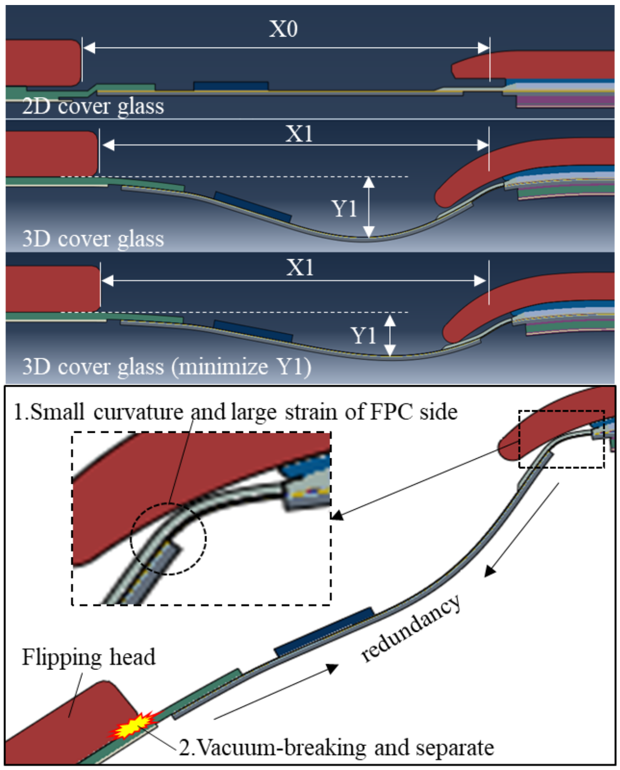

Figure 7. The difference of bending process between 3D and 2D CG

Using the same trajectory parameters, the flipping head rotates along the red trajectory in Figure 8a. Compared to the ideal trajectory (blue curve), the two curves overlap within the range of S1 before the intersection point, indicating a redundant state, and within the range of S2, indicating an over-pull state. The redundant state leads to two problems: firstly, the FPC side experiences high strain during the process. Secondly, the interface between flipping head and FPC will break vacuum and separate. Similar to 2D CG, over-pulling state will cause excessive strain on the panel side. Therefore, the 3D CG trajectory needs to be corrected. Firstly, try to reduce the Y1 value, thereby reducing the areas of S1 and S2 (Figure 8b). Secondly, reduce L to make the end position of the flipping head the same to the original trajectory (Figure 8c). The problems has been improved, and the strain on the FPC side has decreased, as shown in Figure 9.

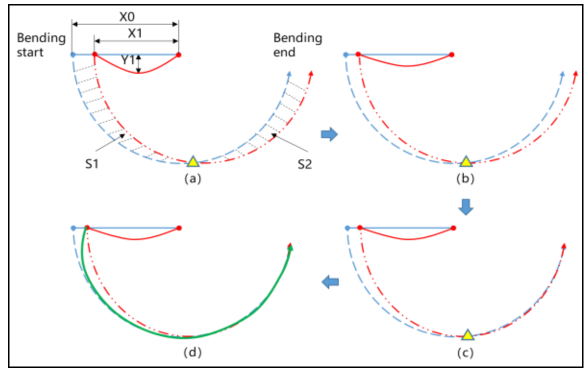

Figure 8. The diagram of 3D CG trajectory. (Blue line: the optimized bending trajectory of 2D CG. Red line: the bending trajectory that changes due to the interference of 3D CG. Green line: the corrected trajectory based on optimized trajectory.)

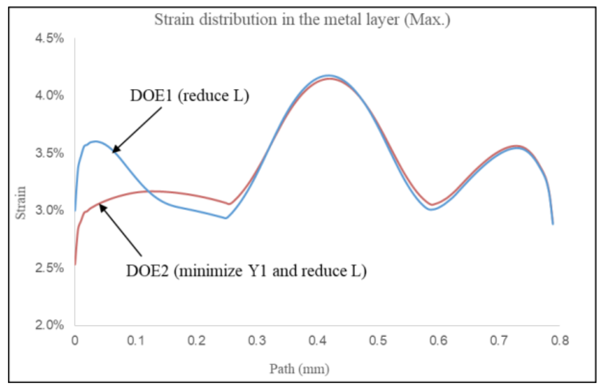

Figure 9. Strain distribution before and after optimization

In the future, as the bending depth of 3D CG becomes deeper, the Y1 value will be larger. The improvement effect of the method shown in Figure 8c will not be enough. Other way, the original trajectory formula of the machine could be corrected based on the green trajectory curve in Figure 8d, as shown in equations 3 and 4. The correction function is a function of the rotation angle θ, and not the only function. In order to reduce redundancy in the initial bending stage and thus reduce strain of FPC side.

$$X = L(1 - \cos\theta) + R \times (\theta \times \cos\theta - \sin\theta) + \varphi 1 \quad (3)$$

$$Y = L \times \sin\theta + R \times (1 - \cos\theta - \theta \times \sin\theta) + \varphi 2 \quad (4)$$

5. Conclusion

This paper presents a method to improve the metal crack during FPC bending process based on simulation. Tightening the BPF slotting size and bonding accuracy helps reduce the impact on the panel side and FPC side, the strain has a minor impact on the center of arc. For 3D CG, which is more difficult than 2D CG, an executable optimization scheme is provided. Comparing simulation and actual failures, we can obtain the threshold of the bending crack, which guides design optimization and process improvement.

6. References

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