Study on the influence of post-treatment conditions on the internal stress of polystyrene products

Chen Jin-wei¹,²*, Yang Ling¹, Wu Li-xuan¹, Chen Da-hua¹,², Mai Qun-shan¹, Weng Qiu-xian¹, Liang Xiang¹, Su Shi-xin¹, Zhang Qi-qi¹

¹ College of Light Chemical Technology, Guangdong Industry Polytechnic, 510300, Guangzhou, China
² Guangdong Polymer Material Processing Engineering Technology Development Center, Guangdong Industry Polytechnic, 510300, Guangzhou, China

*The corresponding author’s e-mail: 2005103052@gditc.edu.cn

Abstract. The polymer products in daily use generally have internal stress, and the uneven or excessive distribution of internal stress will cause warpage or stress cracking, which will affect the normal use of products. Using the heat treatment method of metal annealing to reduce its internal stress for reference, the polymer products were placed in the drying oven and water bath pot for post-treatment, and the influence of different post-treatment process parameters on the internal stress of polystyrene products represented by the mobile phone lens products was studied by using the self-developed molecular material transparent products internal stress detection device. The results showed that increasing the post-treatment temperature below the hot deformation temperature can effectively reduce the internal stress and improve the internal stress distribution of polystyrene products at the same post-treatment time under different post-treatment temperatures and slow cooling conditions, and there was an optimal post-treatment temperature of 60 Centigrade; the polystyrene products after post-treatment had the secondary internal stress under the rapid cooling conditions, so that the internal stress distribution of products was worse than that of polystyrene products without post-treatment. The experimental results can lay a theoretical and practical foundation for seeking effective measures to reduce the internal stress of polymer products in the future.

1. Introduction

With the rapid rise of polymer industry and the development of the times, many polymer products have been widely used in daily life, such as mobile phone screen, optical lens, beverage bottle, etc. The polymer products in daily use generally have internal stress, and the uneven or excessive distribution of internal stress will cause warping deformation or stress cracking of products, thus affecting the normal use of products¹⁻⁴. The reason for the internal stress of products is that the materials after heating and melting are affected by many factors during the processing, resulting in different stress distribution in products⁵⁻⁸. At present, consumers have higher and higher requirements for product quality, so it is of great economic significance to improve the internal stress distribution or effectively reduce the internal stress of products. The research shows that the post-treatment (annealing similar to metal material) can effectively improve the internal structure of the material and reduce the internal stress of the product⁹⁻¹¹, but most of the research focuses on the influence of the post-treatment process on the change of the aggregate structure of the material, while the systematic research on the change of the internal stress distribution of the polymer material under different post-
treatment conditions is rarely reported. In this paper, the internal stress distribution of polystyrene (PS) products under different post-treatment conditions was systematically studied by using a self-made internal stress distribution detection device. As we all know, PS is easy to be processed and molded, and has the advantages of transparency, cheapness, rigidity, insulation, good print-ability, etc. It can be widely used in light industry market, daily decoration, lighting indication and packaging, etc. Therefore, PS products under the post-treatment conditions are studied, and the law of internal stress distribution has very good practical and economic significance.

2. Experimental preparation

2.1. Materials
Polystyrene: GPPS SG-26, transparent injection molding grade, melt mass flow rate 9.0g/10min, produced by Shantou Ocean First Polystyrene Resin Co., Ltd.

2.2. Equipment
Injection molding machine: SA1600/540, Ningbo Haitian Plastic Machinery Group Co., Ltd.; mobile phone lens mold: customized product, Guangzhou modern plastic mold factory; electric blast drying oven: SD101-3A, Nantong Huatai Experimental Instrument Co., Ltd.; electric constant temperature water bath: HH-S4, Shaoxing SuBoYi Instrument Co., Ltd.; internal stress detection device of transparent polymer material: self-developed.

2.3. Self-developed internal stress detection device
The device is designed and developed independently, which mainly uses stress birefringence effect and polarized light interference principle, as shown in Figure 1. The main components of the device are composed of two polarizers, incandescent lamp and online imaging system. It has the advantages of fast and convenient application, simple operation and online real-time imaging. Moreover, the detection device has a wide range of applications and can be used in medical products, automobile manufacturing, food and beverage packaging, high-end optical products and other industries. At present, the device has been patented [12].

2.4. Experimental scheme
Under the same injection molding process conditions as shown in Table 1, the PS lenses are injected with injection molding machine for the post-treatment experiment. The PS lenses are post processed by using drying box and water bath pot with different process conditions, and the corresponding post-treatment process parameter setting range is shown in Table 2. The self-developed internal stress detection device is used to detect the internal stress of PS products under different post-processing conditions. The placement position is shown in Figure 2, and the imaging system provided by the
device is used to record the results. Finally, the internal stress distribution images of PS products under different conditions are compared and analyzed, and the change rules are summarized.

### Table 1. Plastic molding processing parameters

| Processing temperature (°C) | Injection pressure (MPa) | Injection speed (%) | Holding pressure (MPa) | Holding time (s) |
|-----------------------------|--------------------------|---------------------|------------------------|-----------------|
| 180                         | 60                       | 25                  | 50                     | 5               |

### Table 2. Post-treatment processing parameters

| Drying oven setting temperature (°C) | Water bath setting temperature with slow cooling (°C) | Water bath setting temperature with rapid cooling (°C) | Storage time in drying oven (min) | Placing time in water bath (min) |
|-------------------------------------|------------------------------------------------------|------------------------------------------------------|----------------------------------|---------------------------------|
| 40~80                               | 40                                                   | 0                                                    | 30                               | 10                              |

**Figure 2. Instruction of productions placement location**

3. **Results and discussion**

3.1. *The internal stress analysis of PS lens under different post-treatment temperature and slow cooling conditions*

The PS lens is post treated for 30 min in the electric blast drying oven at different temperatures, the product is taken out and immersed in a constant temperature water bath filled with 40°C liquid water for 10 min with slow cooling condition, and then the internal stress distribution is characterized by using the self-developed internal stress detection device. The corresponding internal stress distribution pictures are shown in Figure 3.
Figure 3(a) is the stress distribution diagram of PS lens without post-treatment, and Figure 3(b)(c)(d) are the stress fringe distribution diagram of PS lens measured after 30min at different temperatures under slowing cooling conditions. Comparing without the post-treatment PS lenses the color of stress stripe at the edge of PS lenses changes from blue to light yellow, and the width of yellow stripe increases after the post-treatment in Figure 3(b)(c)(d), which indicates that the internal stress decreases. When the post-treatment temperature is 60 °C, the stress fringe color of PS lens is lighter than that of 50°C, which indicates that the stress decreases and the distribution is better; when the post-treatment temperature continues to rise to 70 °C and 80 °C, the changes of the stress fringe color and distribution of PS lens are not obvious, which indicates that the stress distribution and value of PS lens are at its best when post-treatment temperature is 60 °C.

3.2. The internal stress analysis of PS lens under different post-treatment temperature and rapid cooling conditions

The PS lens is post treated for 30 min in the electric blast drying oven at different temperatures, the product is taken out and immersed in a constant temperature water bath filled with 0°C ice water for 10 min with rapid cooling condition, and then the internal stress distribution is characterized by using the self-developed internal stress detection device. The corresponding internal stress distribution pictures are shown in Figure 4.
Figure 4. The stress fringe distribution photos of PS products under different post-treatment temperature and rapid cooling conditions

Figure 4(a)(b)(c)(d) are the stress fringe distribution diagram of PS lens measured after 30 min at different temperatures under rapid cooling conditions. It can be seen from Figure 4 that the internal stress of PS lens after post-treatment and rapid cooling has not been improved correspondingly, and the color of stress stripe is deepened instead, especially at the corner of PS lens, which indicates that the stress concentration at the corner causes the stress to increase. This is due to the secondary internal stress of polystyrene products under the condition of rapid cooling, which makes the internal stress distribution of PS lenses worse than the PS lens without post-treatment.

4. Conclusion
In this experiment the influence of different post-treatment conditions on the internal stress of typical PS products represented by mobile phone lenses was studied. Under the same post-treatment time, different post-treatment temperatures and slow cooling conditions, increasing the post-treatment temperature below the thermal deformation temperature can effectively reduce the internal stress and improve the internal stress distribution of polystyrene products, and there is an optimal post-treatment temperature of 60°C. After the post-treatment, the polystyrene products have secondary internal stress under the condition of rapid cooling, so that the distribution of internal stress in the products is worse than that of the polystyrene products without post-treatment. The experimental results can lay a theoretical and practical foundation for seeking effective measures to reduce the internal stress of polymer products in the future.

Acknowledgments
Authors wishing to acknowledge assistance or encouragement from colleagues, special work by technical staff or financial support from the characteristic innovation project of Guangdong Provincial Department of education in 2019 (2019GKTSCX014), the open fund project of key scientific research and innovation platform of Fujian Institute of Engineering in 2019 (KF-C19004).
References
[1] DI C F, HU R Q 2017 Some Discussion on Internal stress of Automobile Plastic Parts Plastics in Shanghai. 1 pp18-22
[2] Guo G Y 2015 Analysis of the lowering of the internal stress of PS moulding Journal Of XinYu College 10 pp24-26
[3] Wu L Y 2001 Analysis of Inner Stress of Thermoplastic Injection Products Plastics Sci.& Technology 01 pp 28-33
[4] Xu W L 2006 Research on Residual Stress and Optical Performance of Transparent Injection Molded Parts Doctoral Dissertation.
[5] FAN L F 2018 Discussion on the formation mechanism and elimination method of internal stress in injection molded parts Technology Innovation and Application 17 pp18-12
[6] WANG S F 2009 Brief Talk about Stress cracking of plastic products China Science and Technology Information 12 pp182-184
[7] DING Y X, WEN S D 2003 Discussion on the factors influencing the internal stress of plastic injection products Journal of Chengde Teachers College for Nationalities 02 pp68-69
[8] LONG W B 1985 Reduction and dispersion of internal stress in plastic injection parts Application of Engineering Plastics 4 pp23-28
[9] ZHANG Y, Wu C F, YU M H 2014 Internal Stress Relieving of Polymer Waste Material and Its Service life Prediction Journal of Material Science & Engineering 32 pp1046-1050
[10] YANG C, ZENG H M, YAN Y H 1992 Effect of heat treatment on the thermal behavior and structure of PES Aerospace Material Technology 52 pp11-14.
[11] LIU Y J, GUO W H, SU Z Z 2009 Effect of Compatibilizer on the Crystallization of Recycled Poly(Ethylene Terephthalate)/Poly(Ethylene Octene) Blends Polymer Materials Science And Engineering 25 pp62-65
[12] CHEN J W 2019 A testing device for measuring internal stress of transparent products China patent ZL2019204171572.2