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Research on Influence of Different Processing Parameters on the Foam Structure of Tensile Spline

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Abstract. The paper studied the influence of processing parameters on the foam structure based on numerical simulation of tensile spline. Using CO_2 and N_2, single factor experiment method was employed to perform the experiments. In the study, volume filled at start of foaming, initial bubble radius, volume filled at V/P switch, injection time, mold temperature and coolant temperature were selected to study their effects on the foam structure of tensile spline. Finally determine the optimal processing parameters combination which verified by the experiment.

Introduction

The microcellular foaming technology was appeared in early 1980s [1], this method, which is researched intensively in the late several years, used widely in the area of aviation and automobile etc. Microcellular plastic has maximum limitation to alleviate the weight of products and reduce cost. Certainly, microcellular foaming plastic is deficient at depressed mechanical property, poor surface quality and complex process technology, as a result, it needed a mass of research in this technology in order to promote industrialized application.

Te Luo [2] has been experimented effect of Process Parameters on Cell Morphology in microcellular foaming of PC/ABS. Tianqi Li[3] found the effects of process conditions on the cell structure which foamed by supercritical CO_2. Dongxiao Zhao [4-5] modified theoretical model to get a more realistic mathematical model of the nucleation process, then the corrected theory model was applied in PS/N_2 system. Qian Zhang[6] studied the apparent mass, cellular structure and mechanical properties by special nozzles and mold. Yuechao Li[7] investigated the effects of the inject temperature, inject pressure, SCF inject volume and inject rate on PP foamed material. Yangmi Hao[8] researched on influence and prediction of processing parameters on the properties of microcellular injection molded thermoplastic polyurethane based on an orthogonal array test. Kwon.Y.K. [9] carried on experiment with the effect of the saturation temperature and pressure on cell.

CO_2 and N_2 are environmentally friendly blowing agents, and can be got from the air. On account of the different physical parameters, the ability of solubility and diffusivity in the polymer is varied to CO_2 and N_2, which brings about property change of product.

At present, relevant studies that the effect of different physical blowing agents on micro-foamed polymer materials are relatively little, which greatly limits the microcellular foam wide range of commercial applications. Therefore, this paper presents the influence of plastic on the different foaming agents and process parameters.

Experimental setup

Materials

Thermoplastic Material

PP was provided by Hostacom SDT 11, Basell Polyolefins North America in the material database of Moldflow. It was used 5% by weight relative to the Talc content as filler.

Foaming Agent

CO_2 and N_2 was selected as the physical foaming agent.

Experimental Model

The standard tensile sample was selected as a research object according to GB/T1040, which was moulded as the following size: Overall length (L=165mm), Distance between the two fixture (H=115mm±1mm), Length of narrow parallel-sided portion (C=80mm±2mm), Gauge length (Ga=50mm±0.5mm), Width of parallel-sided portion (b=10mm±0.2mm), Width at ends (W=20mm±0.2mm), Normalized thickness (d=4mm±0.2mm), Radius (R=4mm±0.2mm), which is shown in Fig.1. Three-dimensional model was established by UG in accordance with the above dimensions, which is imported in Moldflow software with grid division, Hence, the gating system and cooling runner are established according the standard mold design guidelines, as shown in Fig.2.

Experimental Method

The simulation analysis aims to reveal the influence rule of cellular structure on microcellular injection molding with two different blowing agent in the six processing parameters, which was used by single factor experimental way.

When it is studied the influence of a particular factor by the changing of target parameter. There are a total of 42 tests in six groups in the simulation, and the test scheme is shown in table 1. For convenience, the logogram of parameters is list as following: V represents volume filled at start of foaming, and R_0 stands for initial bubble radius, V/P means volume filled at V/P switch, t_{inj} represents inject time, T_{mold} means mold temperature, $T_{coolant}$ stands for coolant temperature.

Table.1 Parameters level

Factor	Level 1	Level 2	Level 4	Level 3	Level 5	Level 6	Level 7
V(%)	86	88	92	90	94	96	98
R_0(μm)	0.6	0.7	0.9	0.8	1	1.1	1.2
V/P (%)	93	94	96	95	97	98	99
t_{inj}(s)	0.7	0.8	1.0	0.9	1.1	1.2	1.3
T_{mold}(℃)	27	31	38	34	41	45	49
$T_{coolant}$(℃)	20	25	35	30	40	45	50

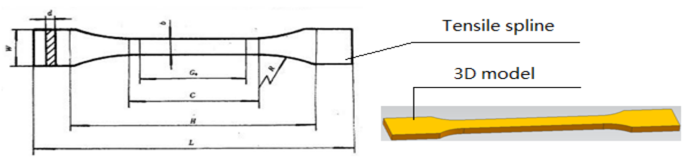


Figure 1. 3D model

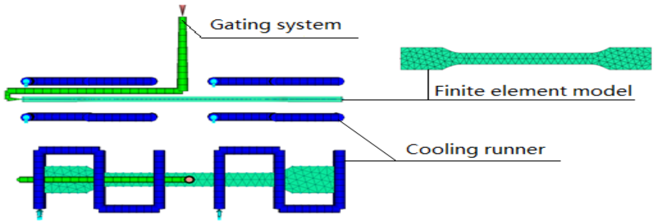
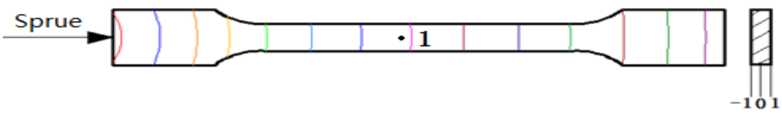


Figure 2. Finite element model

Results and Discussion

As can be seen from the Fig. 3(a), the central point 1 is selected for reacting simulation result in test expediently. The nominal thickness in the central point 1 of sample as depicted in the Fig. 3(b), the thickness of -1 and 1 are presented the surface layer of sample and 0 is core layer. These charts reflect the influence rule of cellular structure on microcellular injection molding.



(a) (b)

Figure 3. (a) Measuring point, (b) Normalized thickness

Effects of Volume Filled at Start of Foaming on Cellular Structure

The distribution of cellular average radius is shown in Fig. 4, which was measured in different nominal thickness of the central point 1 on tensile spline. It can be observed that the value of cellular radius attain the peak in the core layer, and following the far away from the core layer, the cellular radius become small and then reached 0 in the surface layer. The melt temperature in core layer is the highest and close to rampart of die is the lowest, so melt would be solidified near the rampart before the beginning of foaming. The cellular radius on average of N_2 is smaller than CO_2 near transition layer, and is larger near the core layer. The influence of N_2 is much obvious than CO_2 on cellular structure with volume at the beginning of foaming.

Following the increasing of volume filled at start of foaming, the cellular radius on average of CO_2 and N_2 become reduced, as indicated in Fig. 5 and Fig. 6. It can be explained that, the volume of melt filled has direct-effect on the growing space of cell in mold, increased the filling content makes cellular growing space smaller, lead to the minimization of cellular average radius. In addition, the higher pressure is needed for injecting more melt at the equal time, therefore, cellular size is diminishing due to numerous bubble nuclei is generated by accelerated pressure drop rate and higher packing pressure.

The larger the cell, the real effective material to resist external load bearing area is reduced, and with the increasing amount of large cells, the probability of bubble coalescence and collapse rises. As a result, the phenomenon of the stress concentration appears easily in polymer which brings about the limited ability to resist elastic deformation for decreasing the elastic modulus and Poisson's ratio, as is shown in Fig. 7 and Fig. 8. It can be obtained that, the change of the elastic modulus and Poisson's ratio are in the similar direction, and oppose to the trend of the average radius of the cells. The elastic modulus and Poisson's ratio of the core layer are minimum in the nominal thickness, and far away from the core layer, the elastic modulus and Poisson's ratio increases, until the surface is maximized. In the increasing volume of melt way, the same condition happens with the elastic modulus and the Poisson's ratio of CO_2 and N_2.

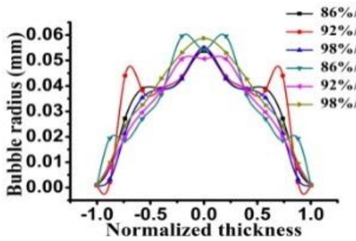


Figure 4. Cellular radius

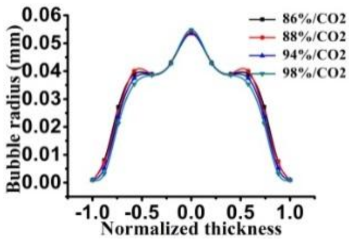


Figure 5. CO_2

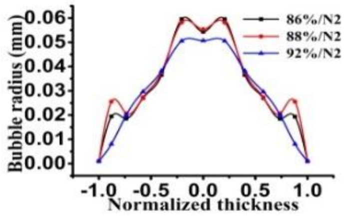


Figure 6. N_2

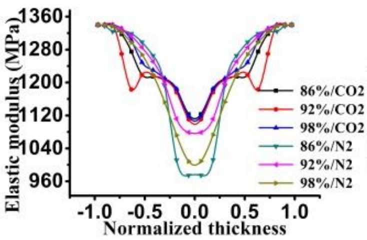


Figure 7. Elastic modulus

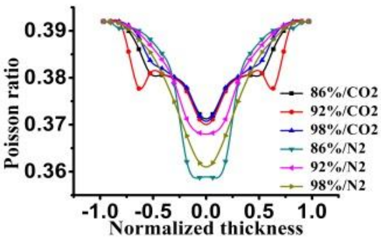


Figure 8. Poisson's ratio

Effects of Initial Bubble Radius on Cellular Structure

With regard to the distribution of cellular average radius on different nominal thickness which is shown in Fig. 9. It can be observed that, the cellular radius of N_2 is smaller than CO_2 near the transition layer, but at a nearby of the core layer, the cellular radius of N_2 is larger than CO_2. Effects of initial bubble radius on N_2 is much significant than CO_2 on cellular structure.

As can be seen from Fig. 10 and Fig.11, with the change of the initial bubble radius in CO_2 foaming, the cells have insignificant variation. For N_2 foaming, the average cellular radius is increased with the increasing of the initial radius, but add up to a certain degree, cells become instability by the larger the initial cellular radius, which makes the decreasing of the average cellular radius.

The change of the elastic modulus and Poisson's ratio are performed in Fig. 12 and Fig.13. With the increasing of the initial bubble radius, the elastic modulus and Poisson's ratio are changed inconspicuously for CO_2 foaming, when it comes to N_2 foaming, elastic modulus and Poisson's ratio are decreased.

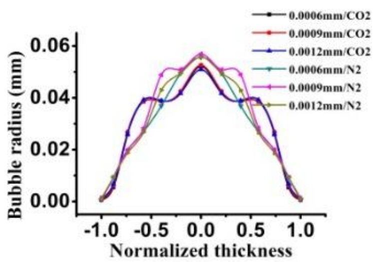


Figure 9. Cellular radius

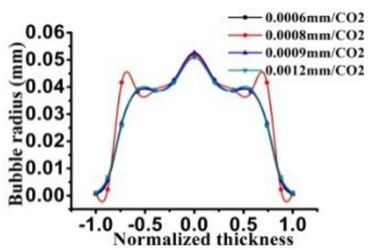


Figure 10. CO_2

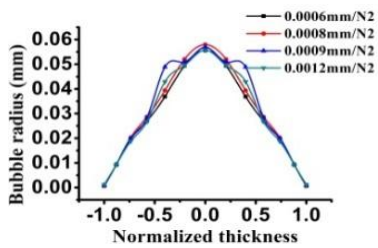


Figure 11. N_2

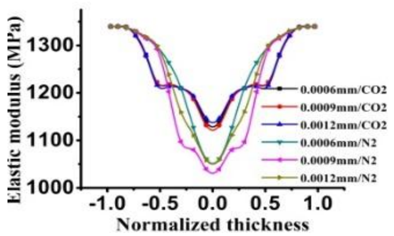


Figure 12. Elastic modulus

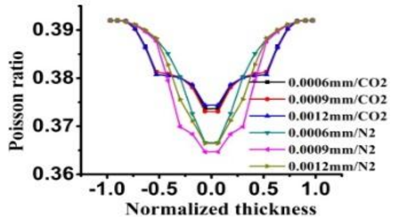


Figure 13. Poisson's ratio

Effects of Volume Filled at V/P Switch on Cellular Structure

Fig. 14 shows that the distribution of cellular average radius within the limits of the nominal thickness. The cellular radius of CO_2 is larger than under N_2 near the transition layer, but smaller at core layer nearby. As can be seen in Fig. 15 and Fig.16, it has no effect of the process parameters on the final bubble radius with various foaming agent.

The change of the elastic modulus and Poisson's ratio are generated by the alteration of cellular structure as it was mentioned above, which is illustrated in Fig. 17 and Fig.18.

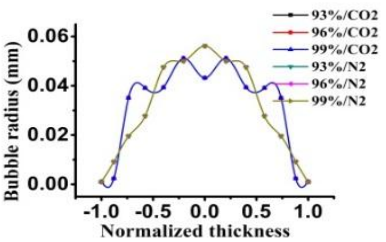


Figure 14. Cellular radius

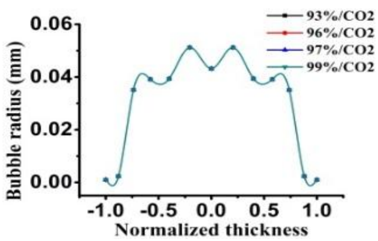


Figure 15. CO_2

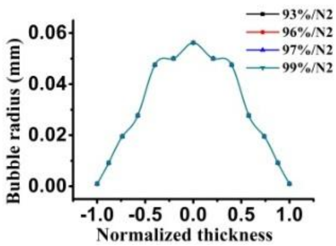


Figure 16. N_2

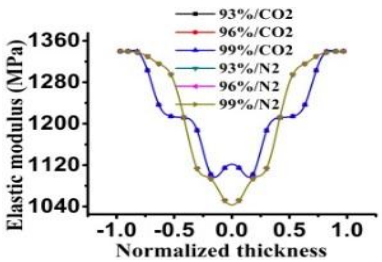


Figure 17. Elastic modulus

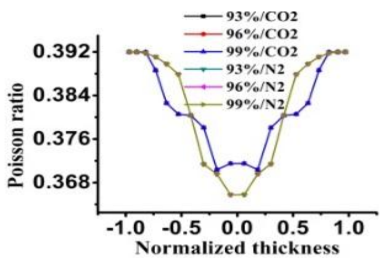


Figure 18. Poisson's ratio

Effects of Injection Time on Cellular Structure

The distribution of cellular average radius on different nominal thickness is shown in Fig. 19. It can be observed that, the cellular radius of N_2 is smaller than CO_2 near the transition layer, but in a larger way near the core layer. Effects of inject time on N_2 is much obvious than CO_2.

For CO_2 foaming, with the extended of injection time, cells that close to surface layer become decreased, which are charted in Fig. 20 and Fig.21. The small final bubble radius is due to the lower solubility of gas in melt and increased bubble nucleus in reducing single gas concentration. Also, following the increasing in the injection time, slow the injection speed and the melt shear rate, the shear heat generation lessen, the melt viscosity and the obstacles of the cell growing rise, result in that the size of cell will be narrow. For N_2 foaming, the cells become large with the longer injection time, on account of the more time to grow up is much useful than the influence of foaming.

Different cellular structure brings the change of the elastic modulus and Poisson's ratio which is mentioned above, as shown in Fig. 22 and Fig. 23. With the added of injection time, for CO_2 foaming, the elastic modulus and Poisson's ratio increase near the surface layer; the elastic modulus and Poisson's ratio decrease for N_2 foaming.

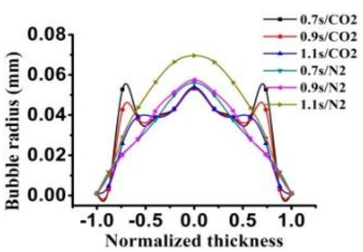


Figure 19. Cellular radius

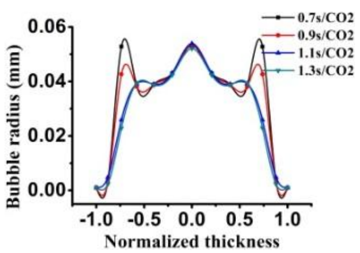


Figure 20. CO_2

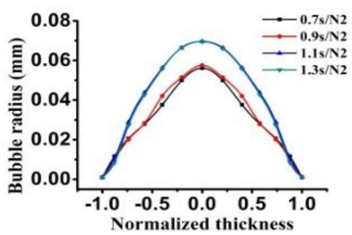


Figure 21. N_2

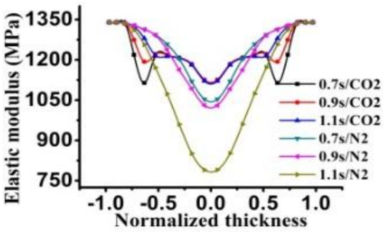


Figure 22. Elastic modulus

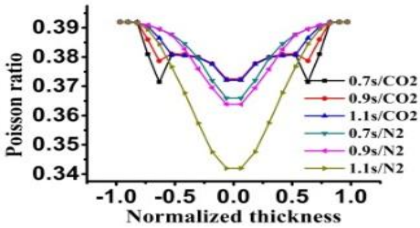


Figure 23. Poisson's ratio

Effects of Mold temperature on Cellular Structure

The distribution of cellular average radius in range of nominal thickness is shown as Fig. 24. At the identical technological parameter condition, the cellular size of N_2 is larger than CO_2.

As described from Fig. 22 and Fig. 23, in regard to CO_2 foaming, the size of cell become large with the increasing of mold temperature, it can be explained that the elevated mobility of melt in mold and the extended the time of cooling, the cells have much time to grow up. For N_2 foaming, it has hardly effect on cellular size.

The change of the elastic modulus and Poisson's ratio are illustrated by different cellular structure mentioned above, which is described in Fig. 27 and Fig. 28. With the increasing of mold temperature, the elastic modulus and Poisson's ratio are decreased for CO_2 foaming; as to N_2 foaming, it has tiny influence on the elastic modulus and Poisson's ratio.

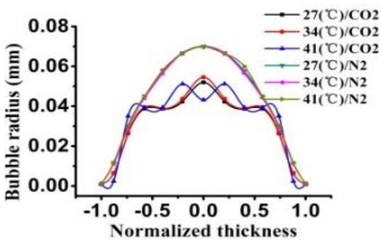


Figure 24. Cellular radius

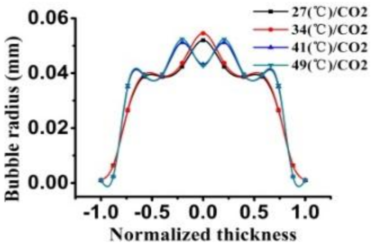


Figure 25. CO_2

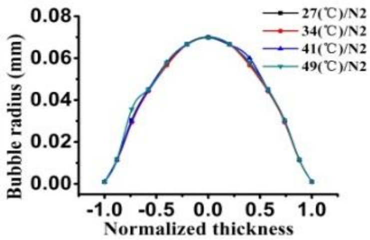


Figure 26. N_2

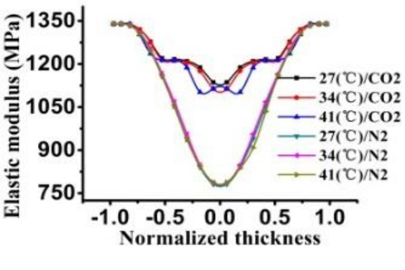


Figure 27. Elastic modulus

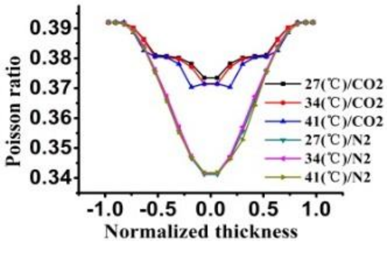


Figure 28. Poisson's ratio

Effects of Coolant Temperature on Cellular Structure

The distribution of cellular average radius along nominal thickness is shown in Fig. 29. The cellular size of N_2 is larger than CO_2 in the uniform technological parameter.

It can be seen in Fig. 30 and Fig. 31, with respect to CO_2 foaming, the cell near the surface layer increase on the premise that the rising of coolant temperature, there is more time for mold to cool down and then bubble can grow up or merge sufficiently. Coolant temperature has insignificant effect on cellular structure for N_2 foaming.

The alteration of cellular structure makes the change of the elastic modulus and Poisson's ratio, as shown in Fig. 32 and Fig. 33.

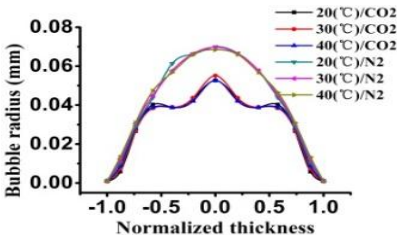


Figure 29. Cellular radius

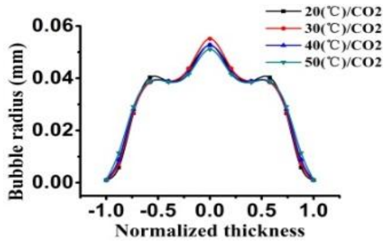


Figure 30. CO_2

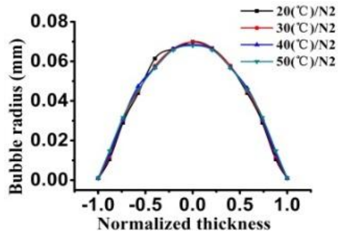


Figure 31. N_2

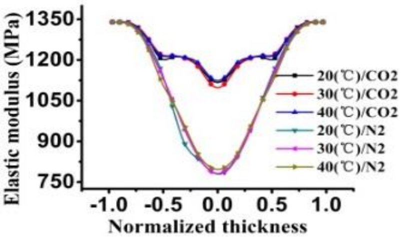


Figure 32. Elastic modulus

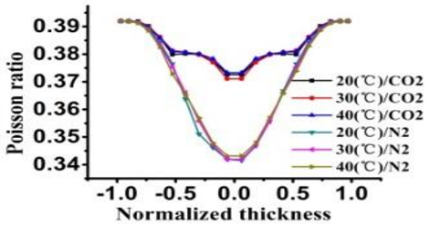


Figure 33. Poisson's ratio

Experimental Confirmation

Above this analysis, it can be achieved smaller and denser bubble structure distribution under the circumstances of the smaller initial bubble radius, lower mold temperature and cooling temperature, and vaster volume filled at start of foaming, more inject time. Combined with the actual situation, N_2 was used for the physical foaming agent. It is necessary to adjust process parameters for getting a superior product.

The SEM image of cross section on the parts was taken under this technology, which is shown in Fig. 34. In light of the SEM image, the bubble radius is well-distributed and in vary of 30 ~ 150 um measure, which can satisfy the performance requirements of the microcellular foaming parts. The tensile strength of the sample was 18.179 MPa under this condition.

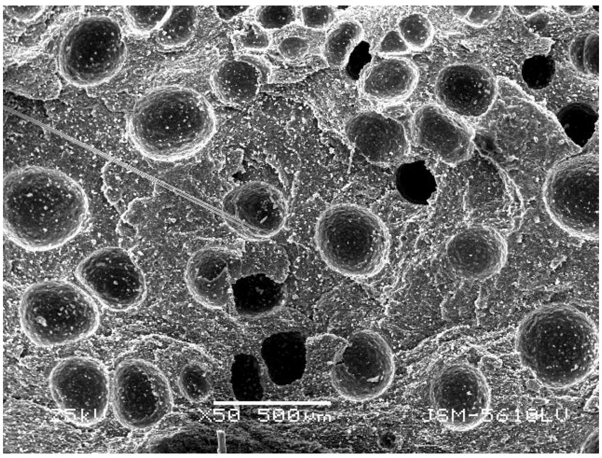


Figure 34. SEM image of cross section

Conclusion

(1) It is consistent with the overall distribution of cell structure, cellular radius was the most biggest in the core layer, and following the farther away from the core layer, the radius become smaller and then reached 0 in the surface layer. The change of elastic modulus and Poisson's ratio are in identical way, and oppose to the trend of the average radius of the cell.

(2) On the basis of the shrinking initial bubble radius, decreased mold temperature and cooling temperature, the increased volume filled at start of foaming and injection time, compact bubble

structure can be obtained; it has almost non-effect to cellular structure with the volume filled at V/P switch.
(3) It was verified that optimize process parameters for getting a preferable microcellular plastic through experiment.

Acknowledgements

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