2.5 D Cavity Balancing

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Abstract: Cavity balancing is the process of altering the flow front within a cavity through thickness and design changes such that the desired fill pattern is achieved. The 2 dimensional (2D) cavity-balancing algorithm, developed by Lam and Seow [1] can only handle 2D geometry. This represents a major drawback as most, if not all of the practical injected parts are not 2D parts. To overcome this difficulty, the present investigation has developed a 2.5 dimensional (2.5D) cavity balancing optimization routine implemented within a 2.5 D finite elements domain. The aim of the automated cavity balancing routine is to reduce product development time and to improve product quality. This will lower the level of prerequisite expert knowledge necessary for successful mold and part design. The automated cavity balancing routine has been developed using the concept of flow paths. The hill-climbing algorithm of Lam and Seow is utilized but modified for the generation of flow paths for 2.5D parts. The algorithm has been implemented in a computer program running as an external loop to the MOLDFLOW software. Case studies are provided to demonstrate the efficiency of this routine.

1. Introduction

Plastic injection-molded parts are generally not flat and thus simplification to 2 D object is not justified. However, they are mostly thin and therefore they may be approximated as 2.5D objects.

Lam and Seow [1] has developed a flow path generation routine for 2D plastic parts. It has demonstrated the potential for automatic cavity balancing. However, 2D-flow path generator could not generate flow paths for 2.5D parts. Thus, a major limitation of the 2D automated cavity balancing routine is the lack of 2.5D flow path generator.

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2.5D flow paths are complicated and they may not be visualized easily. For cavity balancing of practical parts, the development of a routine for 2.5D flow path generator is critical. Figure 1 depicts same possible flow paths in a 2.5D part [2].

A convenient way of generating a 2.5D flow path is to utilize the domain of the finite element mesh. Since hill-climbing algorithm has been proven that it is robust and effective for creating flow path for
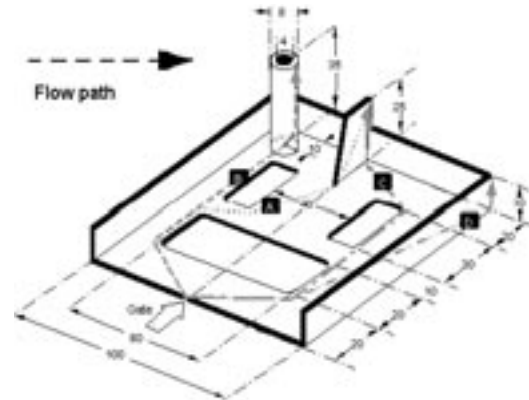
2 D cavity balancing [1], this algorithm will be modified and extended to 2.5 D parts.

Figure 1 Showing possible flow paths A, B, C and D [2]

An important consideration in cavity balancing is the varying wall thickness of a part. However, not many studies have shown the effects of varying wall thickness on part quality. Bernhardt [3] presented a computer program, integrated with flow simulation, to evenly fill a mold cavity. In molding the part, it was laid flat into a number of sections, and the different section thickness were then used to balance the melt flow in terms of fill time and pressure. Shoemaker et al. [4] presented a process of packing optimization using packing simulation. Two versions of a part were comparatively studied for uniformity of shrinkage: one with a nominal wall thickness, the other with varying wall thickness. They concluded that when molded parts do not follow the general rules of uniform wall thickness, a compromise has to be made between the uniformity of volumetric shrinkage within each wall thickness and the uniformity of volumetric shrinkage of the entire part. They suggested the use of warpage analysis to verify the effects of shrinkage.

Lee and Kim [5] introduced a concept for deliberately varying the wall thickness of an injection-molded part within a prescribed dimensional tolerance to reduce part warpage. Warpage was obtained from warpage simulation and represented various deformation behaviors of the molded part. Considering the variation in molding process as noise factors, a wall thickness model that minimized the effect of these noises on warpage characteristics was obtained using the Taguchi method. The warpage characteristics of the varying wall thickness models were compared with those of the constant-wall-thickness models. Each model was then simulated for plausibly small process fluctuations against the best process conditions that would occur in the actual molding operation. The conclusion was that the varying wall thickness model exhibited better warpage characteristics in terms of warpage value and variance against this value, when compared to the constant wall thickness model.

A concept for deliberately varying the wall thickness to reduce part warpage is presented here. In doing this, we will first address the limitation of 2 D flow path generation in more details. By making use of hill climbing algorithm, a new method to create flow path in 2.5 D model will be presented. Finally automatic optimization routine for 2.5 dimensional injection-molding parts will be illustrated by examples.

2. LIMITATIONS OF THE 2D FLOW PATH GENERATION

The main shortcoming of 2-dimensional flow path generation [1] is that the flow path is created only by utilizing the global coordinates (x, y) of the part. There is no checking during flow path generation if the flow path has crossed an elemental boundary. As show in figure 2(a), this global definition is perfectly adequate for a 2D part, as all points of a flow path will be contained on a plane.
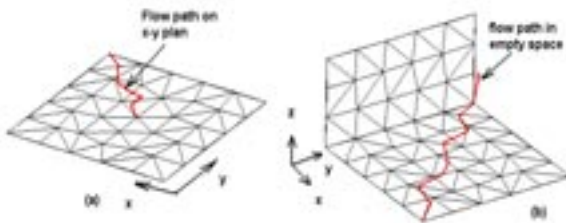

Figure 2 Limitation of the 2D-flow path generator

While in 2.5D, the flow path should be located on the surfaces of a part. However, the surfaces are oriented arbitrarily on the XYZ plan. If the 2D algorithm is adopted as it is, there exists the

possibility that the flow path will go out of the surfaces and into the empty space, see figure 2(b).

3. 2.5 D FLOW PATH GENERATION

As shown in figure 3, a part is created by surface, and surface can be divided into elements by meshing. Thus, for 2.5 D finite element simulation, the physical domain is approximated by faceted surfaces defined by elements. Each element is planar and therefore two-dimensional. Thus, instead of using global information for flow path generation and definition, local elemental data could be used. Flow path could be created within the elemental 2D domain, even though this domain or the overall mesh is in a 3 D space. The major advantage of this concept is that it simplifies the 2.5D problem into a series of 2D problems. The details of the proposed routine will now be discussed.
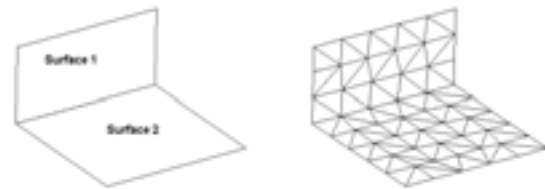

Figure 3 Two-dimensional linear triangular element

3.1 Flow path generation

Flow path can be generated by tracing the flow of polymer from each boundary nodes of the part back to the injection gate. The objective function employed is fill time $F(x)$. At the injection point, the fill time $F(Inj) = 0.0$. At the extreme or the furthest boundary node along any flow path, the fill time $F(Bnodes) = f_{max}$ for the flow path. The flow path can be generated by hill-climbing algorithm, which is discussed in detail by Lam and Seow [1] and will not be repeated here. Basically, through the algorithm, the steepest descent in term of filling time is found from the boundary node to the gate. The path traced is the flow path. Hence from the fill pattern created by the filling analysis, we can track a flow path from any location within the cavity back to the injection node.

Flow path generation is obtained stepwise. During each step, the direction and step length of the steepest descent are determined though two types of searches, which are approximate search and precise search.

3.2 Flow path generation routine

As discussed in the previous section, flow path generation can be reduced into a series of two-dimensional searches within the elements. An

of flow path between one element to the next. This can be achieved by ensuring that the flow path generated always reaches the edge (or in special cases, the node) of the element but not extended beyond the element. Continuity of the flow path into the next element is achieved by having the search of the flow path on the next element starting from the point of intersection between the flow path and the common edge. The steps are:

Step 1:Read all the nodal and elemental data.

Step 2:Begin path generation from one of the boundary nodes, BN=1 to NBN.

Step 3: Initialization, set the starting point P and its co-ordination x, y, z to 0, P=0, X(p)=0, Y(p)=0, Z(p)=0.

Step 4: Read all element numbers with the same boundary nodes BN.

Step 5: By using the strategy of flow path creation introduced in the last section, calculate the filling times within all the elements in step 4 and determine the point p+1 with minimum filling time f_{min}.

Step 6: Increase P = P+1, updating the coordinate of point p to p+1 and thus
$$X(p) = X(min), Y(p) = Y(min), Z(p) = Z(min)$$

Step 7: Check whether point p is near to the injection point. If yes, go to step 13, if no, go to the next step.

Step 8: Check the location of point p.

•   If point p is at the edge of the element, go to step 9(a).

•   If point p is at the middle of the element, go to step 9(b).

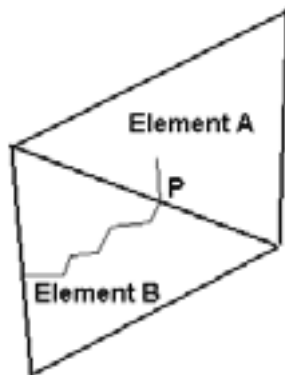•   If point p is at the node point, go to step 9 (c).

Figure 4 Point P at the edge of the element

Step 9 (a): Detect the adjacent element number and switch to that element. As indicated in figure 4, flow path stops at the edge of element B and switch to element A. By using the strategy of flow path

the filling times of the points within element A and determine the point with minimum filling time f_{min}. Go to step 10.

Step 9 (b): By using the strategy of flow path creation introduced in the last section, calculate the filling times of the point in the middle of the element and determine the point with minimum filling time f_{min}. Go to step 10.

Step 9(c): Obtain all the adjacent element numbers with that common node. As shown in figure 5, Flow path was created in element D and reached node N. The program will determine all the adjacent elements that shares node N. In this case, we will get elements A, B, C, E, F. Calculate the filling times of all the elements with node N as the origin and determine the minimum filling time f_{min}. If point P happens to be in element A, subsequent flow path generation will continue in element A.
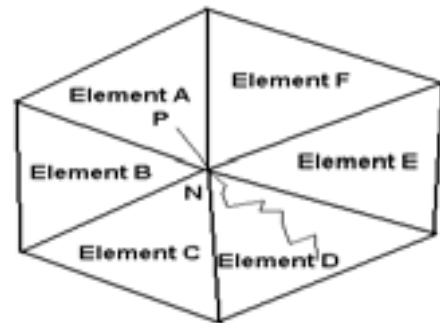

Figure 5 Point P at the node of point

Step 10: Go to step 6

Step 11: End

It should be noted that the step length is pre-determined. However, if from point P to the edge or the node is less than the step length, the program will automatically reduced the step as the length from P to the edge or the node for the current search. This consideration is applicable to steps 9 (a), 9 (b) and 9(c).

4. 2.5 D AUTOMATIC CAVITY BALANCING

Finite element analysis of plastic injection molding has an advantageous feature that it allows each element to have a unique thickness, which in turn will influence the fluidity. Hence, by altering the thickness for each of the elements, the flow rate can be controlled at the elemental level, and thus the fill pattern. By having the flow front reaches the boundary of the edges of the cavity simultaneously, a balanced cavity can be obtained.

To achieve automatic cavity balancing, flow

time for all the elements or nodes. Flow paths are then generated as described in the previous section. New thickness will be assigned to each of the flow path according to the fill time of the boundary node from which this flow path is generated. Subsequently, the element thickness is determined by averaging the thickness of the flow path(s) passed through it. The process is iterated until an optimality criterion is satisfied. The details of this procedure will now be described.

4.1 Optimization parameter

Warpage in plastic injected part could be reduced by having a balanced cavity. The process of balancing the cavity occurs primarily through adjusting the fill pattern. A similar approach as described by Lam and Seow [1] will be adopted here. As thickness has a direct relationship to flow rate, it is chosen as the optimization parameter. It is necessary to relate the continually updated fill pattern to the thickness. The aim is to have all the boundary nodes having the same fill time.

The fill time and thickness of a cavity can be expressed approximately as a simple ratio. As such, the following equation can be used for updating the thickness:

$$Z_{new} = \left(\frac{t_{bn}}{t_{ref}} \right) \times Z_{old} \qquad [1]$$

where

Z_{new} is the updated thickness of the boundary node

Z_{old} is the current thickness of the boundary node

t_{bn} is the time when the melt front reaches the boundary node

t_{ref} is the time when the melt front fills the reference node (normally a boundary node).

Indeed, the thickness Z is the thickness associated with each flow path. This thickness is used to calculate other elemental thickness along the flow path.

The fill time $t_{ref.}$ is used as a reference where all other fill times can be compared. If the initial thickness distribution is uniform and the fill time of the flow path with the shortest length is selected as $t_{ref,}$ it would result in an increase of thickness for all other flow paths. Conversely, a decrease in thickness for other flow paths would result if the fill time of the longest flow path is selected as $t_{ref..}$ Fill time of any other flow path can be used. In this case, the thickness for flow paths longer than the reference flow path would increase, and the thickness for flow paths shorter than the reference flow path wold decrease. In the present investigation, fill time of the shortest flow path is

4.2 Optimization Criterion

Iteration will be terminated according to the optimality criterion as suggested by Lam and Seow [1]:

$$Optimality = \left(\frac{N}{N_{total}} \right) \times 100 \qquad [2]$$

where

N is the number of zero pressure boundary nodes.

N_{total} is the total number of boundary nodes.

4.3 Optimization Routine

Automated cavity balancing may begin with an unbalanced cavity with an initial uniform thickness. After the gate location has been determined, cavity balancing can be initiated by employing the concept of flow path and thickness correction as discussed previously. The optimization routine is similar to Lam and Seow's [1] 2D cavity balancing routine. The major difference is that 2.5D flow path generation algorithm as described here is employed. The routine has been coded in VC++ and runs as an external loop to the Moldflow filling analysis. Note that it is dependent upon the part geometry and gate location as inputs. As such, if either of the inputs changes, the routine would have to be run again to balance the cavity.

The steps are:

1. Initialize mold cavity

A uniform thickness is assumed. This is more for convenient and non-uniform thickness can easily be accommodated.

2. Flow analysis

Select material and processing conditions, and execute initial filling analysis.

3. Read in all the Data from the Flow analysis result file

Subsequent to flow analysis, model information and the flow results will be stored by the result files for subsequent flow path generation.

4. Flow path generation

By using the strategy described in the previous section and the results from the flow analysis, flow paths are created. The flow path is determined from each boundary nodes to the injection gate. The number of flow paths generated is equal to the number of selected boundary nodes.

5. Updating of boundary node thickness

A reference flow path is selected. For the analyses contained in this investigation, the shortest flow path was selected and remained unchanged throughout the optimization. The reference filling

The new boundary node thickness are updated using Equation 8. This boundary node thickness Z will be assigned to the whole flow path originated from the same boundary node.

6. Updating elemental thickness

The new elemental thickness is calculated by the following equation:

$$Eth_{new} = \frac{Z_{new}^1 + Z_{new}^2 + Z_{new}^3 + ... + Z_{new}^n}{n} \quad [3]$$

where:

Eth_{new} is the thickness of the element

Z_{new}^n is the new thickness assigned to the flow path n

n is the number of flow paths within this element.

7. Rounding off elemental thickness

The new elemental thickness is given to 3 decimal places. If desired, the element thickness may be rounded off, say to the nearest 1 decimal place.

8. Repeat filling analysis

With the new elemental thickness distribution, flow analysis is repeated.

9. Check if the flow is balanced

If the flow has been optimized and the cavity balanced according to the optimality criterion, go to next step. If not, return to step 3 and repeat steps 3-9 until the cavity is balanced.

10. End .

5. CASE STUDY

To test the effectiveness of the proposed 2.5D automatic cavity balancing routine, a 2.5D part was modeled.

The model Intray was used as an example. Considering its symmetry, half the intray was shown. Its length, width and height are 350 mm, 130mm and 80 mm respectively. The model has 152 triangular elements and 93 nodes in total with the injection gate as shown in figure 13(a). The plastic material was GENERIC HIPS01. The processing conditions were that the mold temperature was 50 ^oC, and the melt temperature was 230 ^oC. Flow rate was 113.57 cu.cm/s.

Figure 6(a) shows the initial filling pattern (fill time contours) with a uniform thickness of 2 mm as shown in figure 6(b). As expected, the flow was unbalanced. The centers of the part filled first and the left rim and the far right corner of the edge filled last.
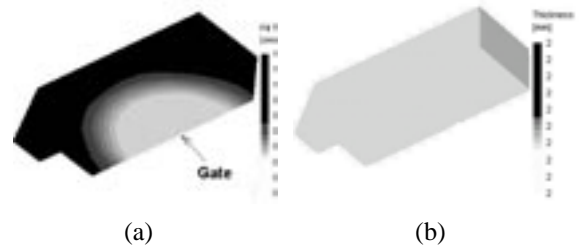

(a)   (b)

Figure 6 Filling pattern and thickness of Intray

After optimization, as shown in figure 7(a), the flows were balanced and reached the edges more or less at the same instance. The final thickness distribution calculated from the routine is shown in figure 7(b).
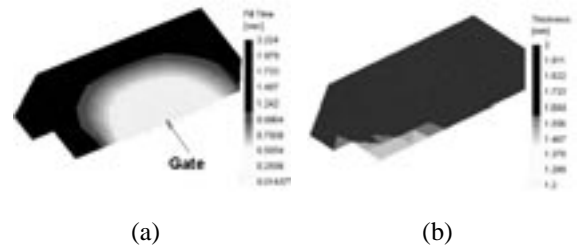

(a)   (b)

Figure 7 Filling pattern and thickness balanced by fill time

Figure 8(a) shows the warpage result of the model before optimization, with a maximum of 13.2 mm. Figure 8(b) shows the warpage results after optimization, with a maximum of 11.27 mm. Thus, through optimization part warpage has been reduced by 14.6%.
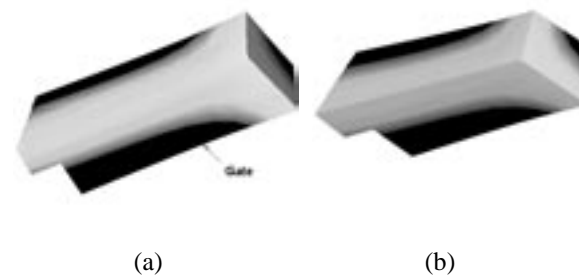

(a)   (b)

Figure 8 Warpage results for intray model (a) before and (b) after optimization

6. CONCLUSIONS

The limitations of the previous work [1] for 2 dimensional optimization cavity balancing routines were discussed. To overcome these limitation, a new method for automated 2.5 D flow path

optimization routine for 2.5D cavity balancing was implemented. The routine was written in VC++ and ran as an external loop to the Moldflow filling analysis. One test model, an Intray, was used to demonstrate the effectiveness and robustness of this technique. The formation of the required flow leaders and flow deflector was clearly evident. The maximum warpage had been reduced through optimization by 14.6%.

7. ACKNOWLEDGEMENT

8. REFERENCE:

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