Title:
Design Analysis and Modification of Ribs and Tubes on Thin-Wall Parts for Mold Flow Analysis

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Keywords:
DFM analysis, design modification, feature recognition, thin-wall part, design guideline.

DOI: 10.14733/cadconfP.2020.106-110

Introduction:
Mold flow analysis has been widely used in injection molding to help with product design, mold design, and process improvement. CAD design may not follow the requirements of mold flow analysis, or it must be modified after analysis. In current practice, mold flow analysis and CAD modeling are often carried out separately by different engineers. When CAD modification and CAE analysis is performed back and forth between different engineers, the entire process is often lengthy and error prone. Design for manufacturing (DFM) is a technique used to evaluate the manufacturability of a design by analyzing the CAD model based on a set of design guidelines. In injection molding, various qualitative and quantitative design guides are generally available. However, a designer may still produce a design that is un-producible or un-acceptable due to a lack of experience, unfamiliarity with design guides, or the complexity of the product. Therefore, the development of a tool that can check the feasibility of a CAD design and modify it for mouldability is helpful for product design.

Research on DFM analysis varies for different manufacturing processes, such as machined parts, sheet metal parts, die-cast parts, and injection parts [1],[2],[3],[5]. The automatic manufacturability analysis of injection-molded and die-cast parts are studied simultaneously as both belong to the molding-type process. Feature-based manufacturing employs features to bridge the gap between design and downstream applications and is the main issue addressed in DFM analysis. Typical features addressed in DFM analysis for injection or die-cast parts include thickness, boss, rib, draft angle, undercut, sharp corner, and fillet. The feature extractor is the most crucial subject in DFM analysis as it determines the kind of features that can be analyzed.

The purpose of this study is to develop a DFM analysis and design modification method for ribs and tubes on thin-wall plastic injection parts. The fundamental issue of this study is presenting a framework for feature recognition of thin-wall parts. A DFM analysis method is then developed to evaluate the feasibility of the dimensions related to several features, such as fillets, ribs, and tubes, based on a set of rules from various design guidelines. A design modification method is finally proposed to modify unqualified rib and tube dimensions automatically. The main contribution of this study is to integrate feature recognition, DFM analysis, and feature modification so that design analysis and modification can be implemented simultaneously. This would enable engineers to perform a trial-and-error analysis and modification of CAD designs during the CAE analysis stage.

<u>Main Idea:</u>

Feature Recognition Algorithm

Fig. 1. depicts the flowchart of the proposed DFM analysis and modification system, which is predominantly divided into two parts: feature recognition and design analysis and modification. In feature recognition, preliminary functions are implemented to prepare the data for protrusion recognition. They mainly provide edge and face databases and fillet and hole data. Edge and face databases record the attributed adjacency of edges and faces, respectively. Fillet data records the type of a fillet and its adjacent faces while hole data records the compositing faces of a hole and its hole type. Fillets and holes must be respectively identified first as they are used at the recognition of auxiliary faces. Protrusion recognition is mainly divided into four steps [4]. Firstly, an algorithm is employed to recognize the inner and outer faces of a thin-wall part. Secondly, auxiliary faces, including transition, wall, and bottom faces, are recognized. Thirdly, protrusion faces that are adjacent to each other are evaluated and grouped. Finally, the feature type of each group of protrusion faces is classified and associated data is outputted. The ribs and tubes of a CAD model can be obtained from the protrusion recognition.

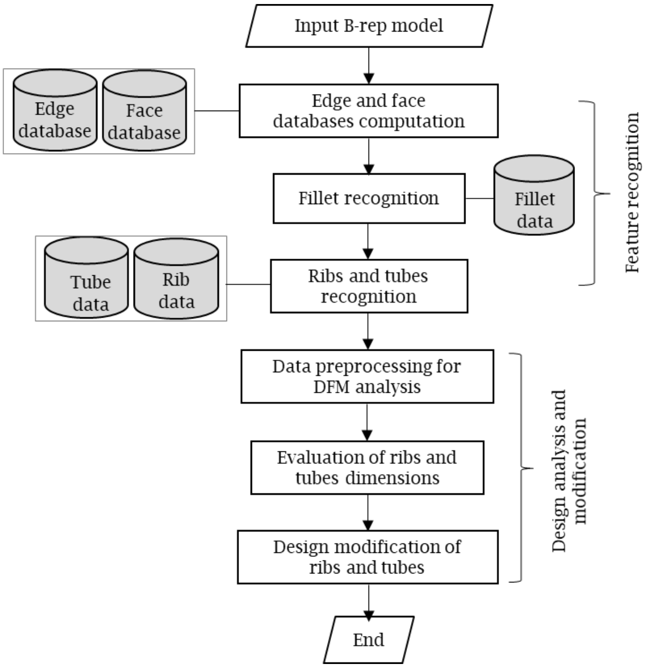

Fig. 1: The proposed DFM analysis and design modification algorithm.

The data structure of features for DFM Analysis must be developed. In feature recognition, the data recorded for a feature primarily only include its face compositions. However, in DFM analysis, the topological data of the edges and faces of a feature is required to evaluate the parameters used in the design guidelines. Therefore, it is necessary to establish a complete data structure for each feature. Ribs and tubes are primarily investigated in this study and sharp corners are usually rounded with fillets. Consequently, the data structure of fillets, ribs, and tubes used for DFM analysis must be developed, and this will be described in the full paper.

Design for Manufacturability (DFM) Analysis

Rib and tube dimensions for DFM analysis are depicted in Figs. 2(a). and (b)., respectively. Rib dimensions include part thickness (t), rib thickness (T_r), rib height (H_r), draft angle (θ_{dra}), rib space (d_r), and base radius (R_r). Tube dimensions include tube thickness (T_t), tube height (H_t), draft angle of tube

(θ_{dra_o}), draft angle of hole (θ_{dra_i}), outer diameter (D_o), inner diameter (D_i), and base radius (R_t). Effective ranges of rib and tube dimensions are determined from design guideliens. The specific range of values allowed for each dimension may vary in different guidelines, but the types of dimensions to be checked are identical. The algorithms for evaluating all rib and tube dimensions on a CAD model will be described in the full paper.

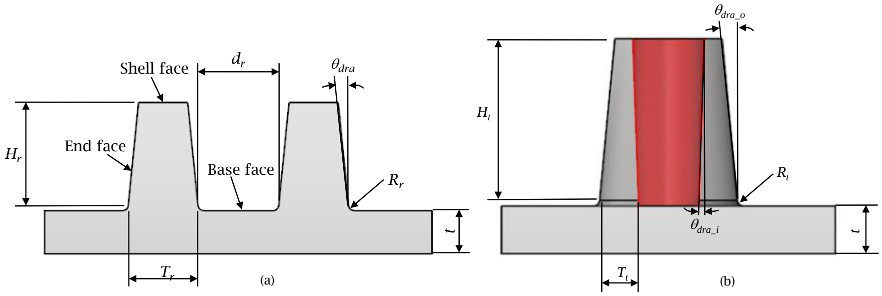

Fig. 2: Parameters used in design guidelines: (a) rib and (b) tube.

After the analysis, unqualified ribs and tubes are colored differently in accordance with the error type. A layer on Rhino (a CAD platform used in this study) was created to display multiple types of errors. Whenever an error occurs on a rib, a parent layer corresponding to this rib is created. A child layer is created when multiple errors for the same rib occurs. A text file was also generated to display all error types in detail.

Design modification of ribs and tubes

The design modification of a rib was achieved by moving a point, edge, or face of the B-rep model with respect to the rib. As the proposed system was implemented on the Rhino platform, the function ON_TransformBrepComponents() on Rhino SDK was employed to achieve the task. Two parameters are specified on this function: (1) the moving vector, $\boldsymbol{V}_m$, required to move an object from points A to B, and (2) the object, O_m, to be moved which can be a point, edge, or face. By specifying different moving objects, O_m, we can achieve the modification of rib width, height, draft angle, and position. The design modification of a tube includes modifications of tube height, thickness, and draft angle, which are primarily achieved through Boolean intersection and difference. Figs. 3(a). and (b). depict the operations for design modification of ribs and tubes, respectively. Detailed description of the algorithms will be described in the full paper.

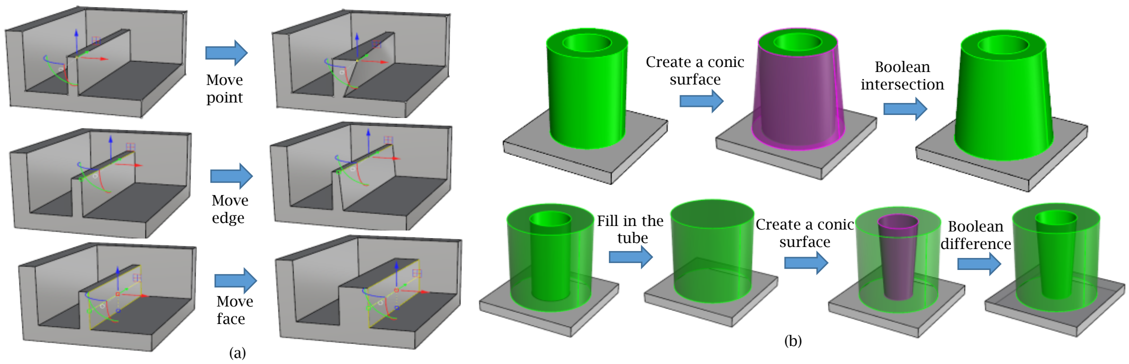

Fig. 3: Design modification of ribs and tubes, (a) through the moving of a point, edge, or face and (b) through Boolean intersection and difference.

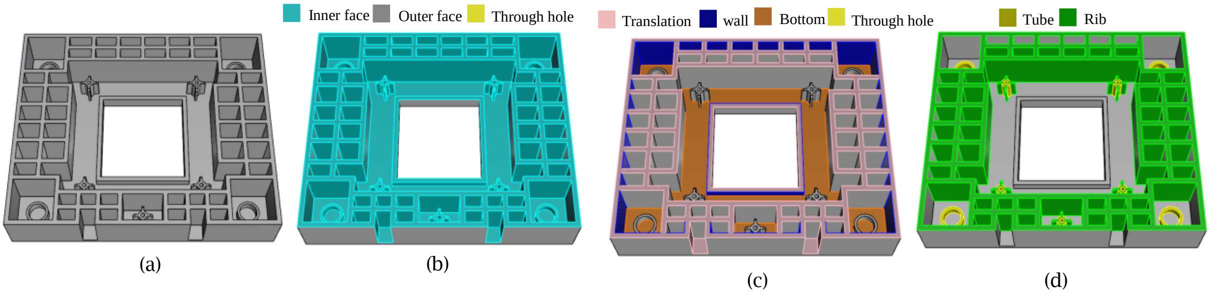

Fig. 4: Results of protrusion recognition for one example: (a) input CAD model, (b) inner and outer faces recognition, (c) auxiliary faces recognition, and (d) classification of protrusion features.

Results and Discussion

The proposed system is implemented in Rhino in an interactive way. Once the proposed system is executed, a CAD model must be selected. The feature recognition algorithm which can yield ribs, tubes, and fillets printed in different colors is then implemented. The next step is determining the mold opening direction, $\boldsymbol{V}_z$. The default direction is along the *z* direction, but the *x* or *y* direction can also be selected. The design guidelines implemented for ribs are rib width, draft angle, rib height, and rib space, and the design guidelines implemented for tubes are tube width, tube height, outer and inner draft angles. DFM analysis of all rib and tube dimensions is then implemented automatically and the corresponding faces of unqualified dimensions are indicated by different colors (as mentioned previously). Rib and tube dimensions can be modified manually or automatically. When manual modification is selected, the user can select the corresponding object (point, edge, or face) on a rib or tube to change its dimensions. Alternatively, when automatic modification is selected, dimensions that can be adjusted include rib width, rib draft angle, tube thickness, and outer and inner draft angles. Once a dimension is selected, all ribs or tubes corresponding to this dimension are modified simultaneously.

The CAD model shown in Fig. 4(a). is employed to demonstrate the feasibility of the proposed DFM analysis and modification system. The input data is a B-rep model of the part and the holes that connect to its inner and outer faces. The hole data can be accessed from the face database obtained in the preliminary functions. Figs. 4(b). to (d). show the immediate results of the protrusion recognition. In Fig. 4(b)., the transition of inner and outer faces is the edges shared by the visible and invisible faces of a part when it is assembled with its counterpart. Fig. 4(c). shows the result of the auxiliary faces recognition, where the auxiliary faces are recognized based on the inner faces obtained in Fig. 4(b). It is noted that when the side wall of a part is higher than its internal features, the translation faces are distributed around the boundary of the inner surface. However, when some internal features are of the same height as the side wall, the translation faces can traverse across these features. Fig. 4(d). shows the result of the protrusion feature classification, where only ribs and tubes exist in this example. The other three protrusion features are columns, polygon blocks, and irregular extrusions.

The result of the DFM analysis and design modification is shown in Fig. 5., where Fig. 5(a). depicts the result of the DFM analysis and Fig. 5(b). depicts the result of the automatic rib and tube modification. Erroneous dimensions found in this example include unqualified rib and tube thickness, and draft angles, as shown in Fig. 5(a). Once the thickness is changed to 1.2 mm and the draft angle is changed to 1°. All ribs and tubes are modified automatically, as shown in Fig. 5(b). Inappropriate thickness design may result in the presence of indentation of the plastic injection product. The main contribution of the proposed method was providing the DFM analysis for the rib and tube dimensions and an automatic modification method to change unqualified ribs and tubes automatically. In mold flow analysis, an original CAD design may not necessarily be satisfied in all features design, which means it is usually necessary to perform design modification and CAE analysis back and forth between design and CAE engineers. With the proposed DFM analysis and modification system, an initial check of all dimensions can be performed before the CAE analysis is implemented, which can reduce the repetition of CAE analysis.

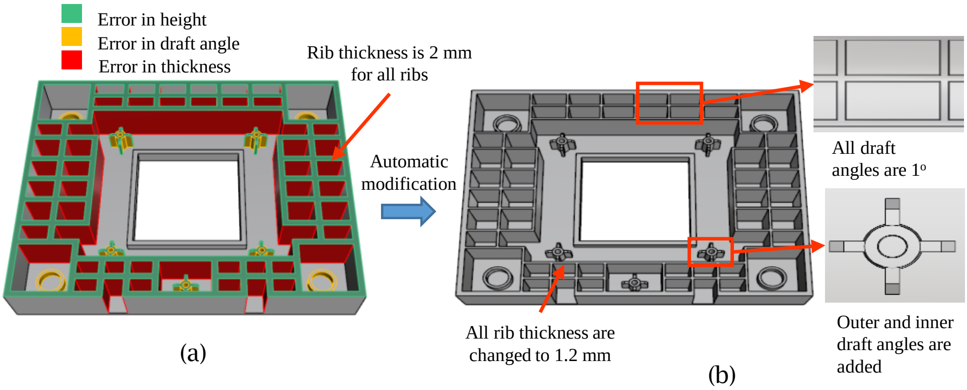

Fig. 5: Automatic modification of unqualified rib and tube dimensions: (a) result of DFM analysis and (b) result of automatic modification.

Conclusions

A DFM analysis and design modification system for plastic injection molding was developed in this study. It primarily involved a feature extractor to extract target features for analysis, a DFM analysis algorithm for the optimization of feature dimensions, and a design modification algorithm to modify unqualified feature dimensions automatically. The DFM analysis and design modification of rib and tube features were investigated in this study. The proposed feature extractor initially recognized auxiliary faces, including translation, wall and bottom faces, on the inner surface of a thin-wall part, and then grouped each set of adjacent protrusion faces. As the auxiliary faces can serve as the boundary constraints for the grouping of protrusion faces, it can reduce the excess of the faces in each group. Each set of protrusion faces could then be classified in sequence, where ribs and tubes were primarily investigated in this study. The proposed DFM analysis algorithm provided a data structure of rib and tube features for the evaluation of rib and tube dimensions. The optimization of feature dimensions included thickness, height, draft angle, base radius, and space for both ribs and tubes in accordance with various design guides. Finally, the design modification algorithm could modify all unqualified rib and tube dimensions automatically. This enables the CAE engineer to perform a trial-and-error analysis and the modification of the CAD design during the CAE analysis stage. In DFM analysis, radii, fillet, draft, undercut, and hole features are also commonly analyzed features. The proposed feature extractor and DFM analysis method can be expanded to cover these features though the design modification of each feature must be studied further.

References:

[1] Bidkar, R. A.; McAdams, D. A.: Methods for automated manufacturability analysis of injection-molded and die-cast parts, Research Engineering Design, 21(1), 2010, 1-24. https://doi.org/10.1007/s00163-009-0070-9

[2] Chan, W. M.; Yan, L.; Xiang, W.; Cheok, B. T.: A 3D CAD knowledge-based assisted injection mould design system, International Journal of Advanced Manufacturing Technology, 22(5-6), 2003, 387-395. https://doi.org/10.1007/s00170-002-1514-9

[3] Deng, Y. M.; Britton, G. A.; Lam, Y. C.: Towards automatic modification in injection-moulded-plastic-part design, International Journal of Advanced Manufacturing Technology, 28(5-6), 2006, 495-503. https://doi.org/10.1007/s00170-004-2388-9

[4] Lai, J. Y.; Song, P. P.; Hsiao, Y. C.; Tsai, Y. C.; Hsu, C. H.: Recognition and classification of protrusion features on thin-wall parts for mold flow analysis, Engineering with Computers, online, 2019. https://doi.org/10.1007/s00366-019-00859-1

[5] McAdams, D. A.; Bidkar, R. A.: Automated manufacturability analysis for injection-molded and die-cast parts, ASME 2003 Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Chicago, USA, 2003.