Asian Journal of Scientific Research

ISSN 1992-1454

Asian Journal of Scientific Research 6 (3): 589-595, 2013
ISSN 1992-1454 / DOI: 10.3923/ajsr.2013.589.595

Combining Expert Formula and Geometric Feature Extraction for Die Design

[1]William K.S. Pao and [2]C. Lin

[1]Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia
[2]Department of Materials, University of Oxford, Parks Road, Oxford, OX1 3PH, United Kingdom

Corresponding Author: William K.S. Pao, Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

ABSTRACT

Die design is a critical phase in extrusion industry for aluminium products with complex geometries. An acceptable die design generally required tedious finite-element analysis and necessitates hundreds of computer simulations, requiring several weeks or months of lead time. In this study, we focused on one particular aspects of extrusion die design, namely the optimisation of the locality of the die orifice and the maximum number of orifice that can be placed in the die head. To achieve this, we combine the medial-axes transformation algorithm, a tool for geometric interrogation and heuristic empirical design formula to locate the optimum die location and proceed to estimate the maximum possible number of die orifice allowed for a given geometries. The analyses show that our proposed algorithm can be implemented easily and results can be obtained almost immediately.

Key words: Die design, expert formula, feature extraction, bearing length, geometries

INTRODUCTION

Extrusion die design is often a trial and error process. A satisfactory (not necessarily optimal) design is mostly dependent on the designer's skill and experience. The most desirable feature in extrusion die design is to achieve uniform exit velocity of the metal at all points along the cross-sectional area of the die cavity. The location and orientation of the die cavity with respect to the center of the die influences the magnitude and direction of the exit velocity at a given point along the die cavity (Ulysse, 2002). This is because according to the classical theory of fluid flow in a pipe, the maximum velocity is always located at the center of the pipe and assumes a parabolic distribution. The farther away from the pipe center, the smaller is the fluid velocity due to the no-flow boundary condition at the fluid-solid interface. On the other hand, the cross-sectional area of the die's cavity also influences the exit velocity since it dictates the volume of mass flow-through. These two factors are believed to be the two most influential factors give rise to non-uniform exit velocity of the metal product. In practice, the die designer uses "bearing length" as a design parameter to adjust the value of exit velocity locally to achieve uniform exit velocity distribution along the die cavity (Lee *et al*., 2002; Lee and Im, 2002). Figure 1 shows the bearing length example for a solid flat-face die and distance BC is the bearing length. The bearing length distribution along section DD is shown in Fig. 2.

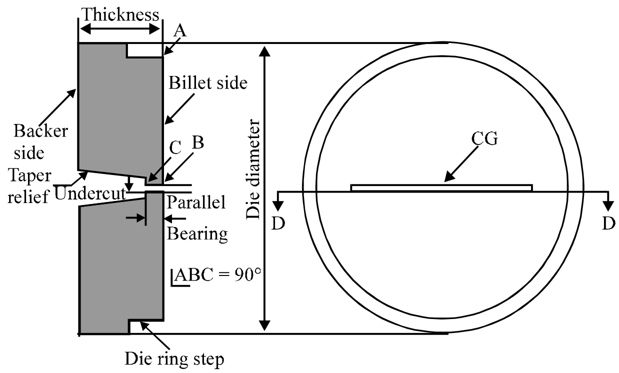

Fig. 1: Example of flat face die head

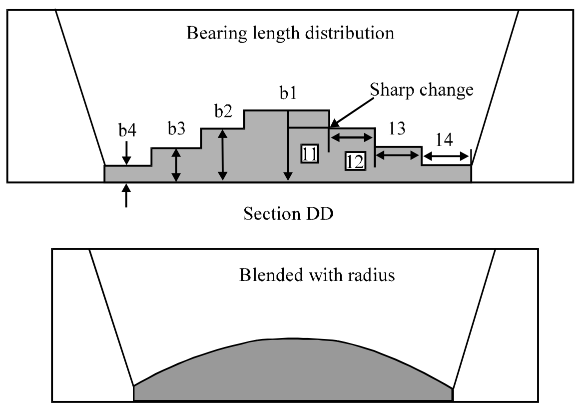

Fig. 2: Bearing length distribution across section DD

By adjusting the values of bearing length along the die opening (b1, b2... etc.), the designer creates a barrier for the incoming metal which exerts a uniform distribution of forces/friction to the metal that ultimately changes the original flow profile. In the industries, there is no clear guideline how the bearing length should be designed with respect to a given die cavity. Numerical simulation such as the finite element method is usually used to simulate the extrusion process and quantitatively predict the exit velocity distribution for a given die geometry. Kusiak and Thompson (1989) applied sensitivities and optimization techniques to design shaped dies for ram loads and uniform exit velocities. Ulysse and Johnson (1999) adopted methods of asymptotic theory to the bearing length design for various profiles. Nagpal *et al.* (1979) used simplified methods to design and manufacture shaped dies with the aid of computer-aided design. Mihelic and Stok (1998) used a Lagrange incremental elastic-plastic 3D finite-element formulation in modeling the metal and considered the optimization of tool design in extrusion and drawing processes. Recent review about die design can be found by Abdullah and Samad (2007) and will not be repeated here.

However, for a multi-cavity die, a three-dimensional simulation is very difficult due to the complexity of the die cavity and most notably, time consuming since the deformation of the extruded metal requires continuous adaptive remeshing. Hence, for a multi-hole die design, the direct use of the numerical method is impractical due to high computational overhead.

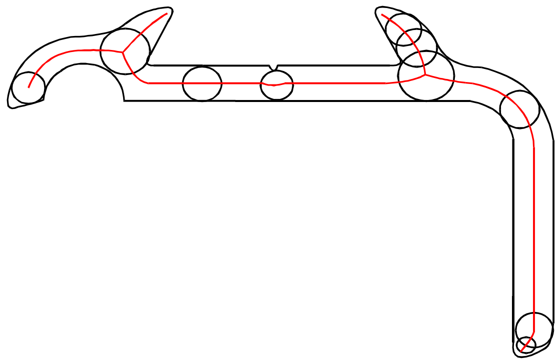

Fig. 3: Example of a two-dimensional MAT

The current work proposed to render this situation by combining the geometric feature extraction and built-in expert's artificial heuristic in the design of the die cavity and its associated bearing length. The work is essentially motivated by the research undertaken by Miles *et al.* (1996, 1997) which proposed a tool for geometric interrogation technique, namely the Medial Axis Transformation (MAT) algorithm. MAT is a lower dimensional skeleton of a surface defined by the locus of the center of an inscribed circle of maximal diameter as it rolls around the object interior. An example of a two-dimensional MAT is shown in Fig. 3. The union of the medial-axis and its associated circle is termed medial object. Due to the degeneration of dimensionality of the medial object as compared to the original geometry, the reduced geometry is easier to manipulate digitally than the original one.

Expert formula: The relation for the bearing length calculation, proposed by Miles *et al.* (1996), is given as follows:

$$b = w(2+C(R-r)) \tag{1}$$

where, b is bearing length at boundary point p, w is the width of section at p which is determined from medial axis transformation, r is the distance of section at p from die center, R is the distance of furthest point of orifice from die center, C is a constant, associated with material, temperature, pressure and other physical conditions. A value 1/80 is proposed by Miles *et al.* (1997). Equation 1 reveals that for a given fixed die cavity, only R and r dictate the bearing length b.

In order to make use of the expert formula and its subsequent embedding in the MAT, the geometry of the die cavity is first transformed into an equivalent medial axis with the medial radius assigned to each junction point. An empirical formula, e.g., Eq. 1, obtained by die designer either via experiments or heuristic reasoning, is used to evaluate the bearing length at every point inside the die cavity. In this study, the optimal orientation and location of the die cavity center is posed as a simple unconstrained minimax problem- i.e., minimize the difference between the maximum and minimum bearing length values. In this optimization problem, the orientation and location of the die cavity need to be changed continuously in order to evaluate the bearing length difference. This poses a great difficulty since any arbitrary points within the die cavity can be used as a reference point. In order to overcome this difficulty, this paper proposed to change the die center relative to the cavity, resulting into two simple design variables which are x and y coordinates of the die center. In other words, rather than moving the die cavity around a fixed coordinate system, we fixed the die cavity and move our coordinate reference point. The next section describes the empirical formula used for the calculation of bearing lengths that is followed by the description of the optimization procedure.

Design algorithm: For a given die center (ordinate of our reference Cartesian coordinate system), the variation of the bearing length along the boundary is first calculated using Eq. 1. The maximum and minimum bearing length of the die cavity are thus determined indirectly. In the next step, the difference (referred as BLD, Bearing Length Difference) is then calculated for each point along the boundary of our die cavity. This calculation takes only fraction of a second on a personal computer. Thus, a BLD value is calculated for a die center location. The processes then repeated for all possible die center locations (Fig. 4).

There are two ways to calculate the BLD value for a given die cavity. The first one is to fix die center and move die cavity to die centre relatively. The other one is to fix die cavity and “move” the die centre relatively. We observed that the first method generates 3 design parameters for optimization as shown in Fig. 4, namely two coordinates (x, y) and an orientation, θ. However, the second method generates only two design variables (x', y') as shown in Fig. 5.

For a fixed die cavity shape, the width of die cavity variation is calculated using MAT. Then an initial location for the die center relative to the die cavity is chosen arbitrarily. The bearing length of the die cavity relative to the current die center is then calculated. Using Eq. 1, the corresponding BLD value can be determined.

As the computational cost is negligibly small, an exhaustive search for all possible optimal centers is equally efficient. Hence, this procedure is carried out for all possible locations of die center relatives to the die cavity. The flow chart of the overall optimization process is illustrated in Fig. 6.

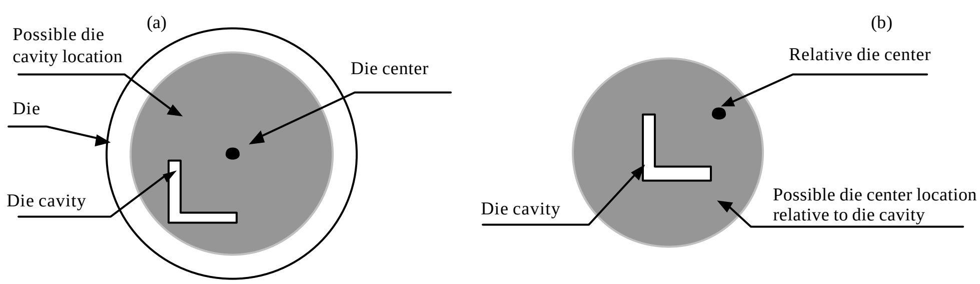

Fig. 4(a-b): (a) Possible location region for die cavities and (b) Relative location region of die center

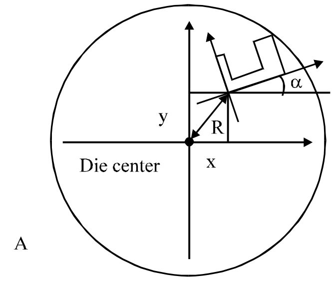

Fig. 5: Variables needed in different coordinate system for bearing length difference calculation

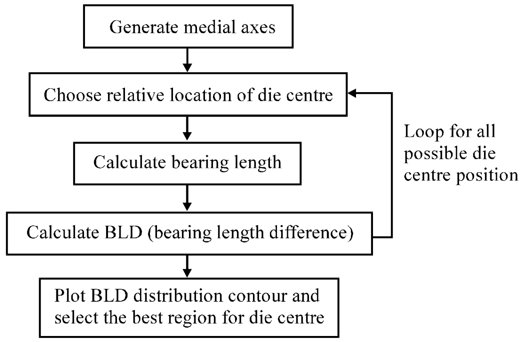

Fig. 6: Flow chart for the proposed optimization process

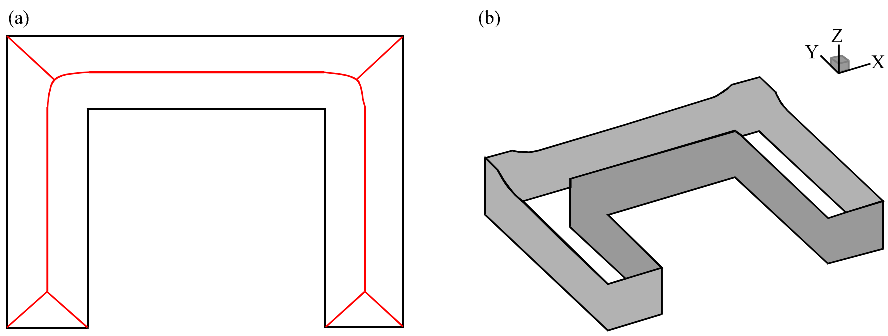

Fig. 7(a-b): (a) U-shaped die cavity design and (b) Its computed bearing length

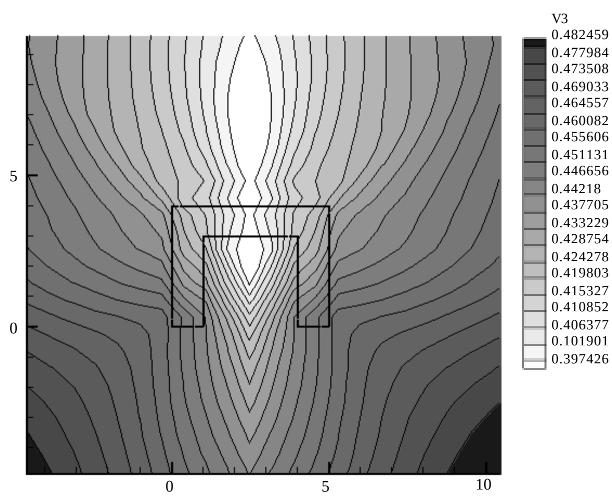

Fig. 8: Contour of the bearing length difference and location of optimum die center

Because smaller BLD means less difference between maximum and minimum bearing length of the die cavity, the position where the lowest BLD value lies can be considered as the best location for die center. This position can be found easily by using BLD distribution contour.

Numerical examples: Here, we illustrate the application of the present algorithm using a U-shaped die cavity, shown in Fig. 7a. The medial axes of the die cavity have been obtained in the

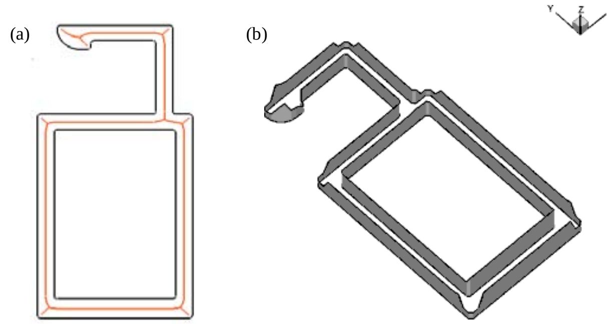

Fig. 9(a-b): (a) Real life die cavity design and (b) Its computed bearing length

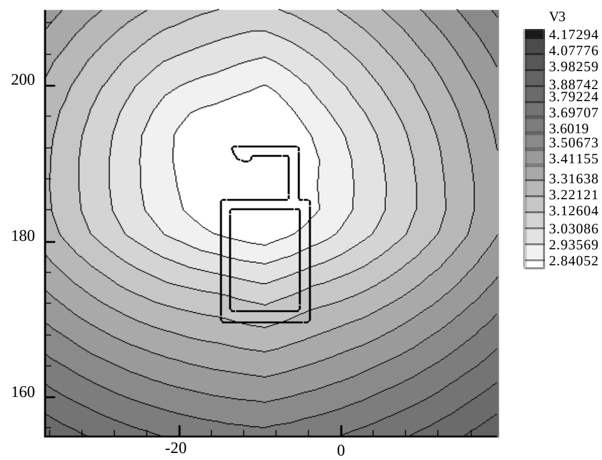

Fig. 10: Contour of the bearing length difference and location of optimum die center

first place using CADfix and the algorithm described in Fig. 6. The bearing length is assumed to be uniformly distributed initially. Figure 7b showed the optimized bearing length.

As expected, the bearing length is thickest at the corner of the cavity and uniformly distributed at all other edges. Figure 8 showed the contour of the bearing length distribution center. The contour with bright shade area indicates the optimum location of the die center for the present die design.

The second example is an industrial case provided by Norsk Hydro Aluminium, Norway, shown in Fig. 9a. Notice that the complex shape of the design prohibits any intuitive guest of the die center. Fig. 9b showed the bearing length distribution. Unlike the previous example, there is no monotonic variation of bearing length thickness around the corners. The BLD contour is shown in Fig. 10. The bright spot indicates the optimum location where the die center should be placed.

CONCLUSIONS

Die design is a critical phase in extrusion industry for aluminium products with complex geometries. In this study, we focused on the optimisation of the locality of the die orifice and the maximum number of orifice that can be placed in the die head. We applied the medial-axes transformation algorithm and combine it with heuristic empirical design formula to locate the optimum die location and proceed to estimate the maximum possible number of die orifice allowed for a given geometries. The analyses show that our proposed algorithm can be implemented easily. We also demonstrated that our algorithm can optimally design the bearing lengths for extrusion dies by taking into account the orientation and location of die cavities.

ACKNOWLEDGMENT

The authors wish to thank Universiti Teknologi PETRONAS for financial support to publish the results in this study.

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