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Minimizing wastage of sheet metal for economical manufacturing

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Abstract

Large quantities of sheet metal are consumed every month in various sectors of industry, the automotive, furniture, white and brown goods, electrical and body building (including coaches and containers) being the chief consumers. A large number of "critical" automotive sheet metal parts lead to rejections leading to wastage of sheet metal during manufacturing. Here, a product that permits a smaller window of variation in material properties compared to that permitted by the standards is said to be "critical". The wastage due to layout (utilization) of blanks on the sheet and that on account of rejections constitutes total wastage. While a number of algorithms are available to maximize sheet utilization and curtail the wastage, there appears to be none to minimize rejections. Thus, it will always be helpful to an industry to use a system capable of predicting and minimizing these rejections at the sheet layout stage. This paper views wastage in totality and attempts to minimize the total wastage arising from layout as well as rejections. Highly strained regions in a sheet metal blank are identified. Based on the permissible window of variation in the material properties, a 'defect map' is generated on the sheet. The blanks are laid out and the possible number of rejections is predicted probabilistically, leading to the prediction of the actual utilization of the material.

Keywords: Rejections; Material utilization; Stamping; Probability

1. Introduction

Large quantities of sheet metal are consumed every month in various sectors of industry, the automotive, furniture, white and brown goods, electrical and body building (including coaches and containers) being the chief consumers.

Sheet metal parts of various levels of complexity are produced rapidly, often in very high volumes, using hard tooling. A product that permits a smaller window of variation in material properties compared to that permitted by the standards is said to be "critical". The material costs can typically represent 75% of total operating costs in a stamping facility. The amount of scrap produced is directly related to the efficiency of the stamping strip layout. Clearly, using optimal strip layouts is crucial for a manufacturing company.

Many algorithms have been proposed to solve the problem of nesting blanks of different shapes on a metallic sheet. The very first algorithms would try to pack the blanks into rectangles of minimum area [1] and repeat the rectangle along the strip. This practice of enclosing the shapes would add a certain amount of waste material to the layout that would prevent the optimum layout from being obtained.

A better approach is the incremental rotation approach [2]. In this the blank is rotated through 180° (due to symmetry) by increments of 1° or 2° and material utilization is calculated at each position. Though these rotation algorithms give good solutions the optimal solution generally falls between the increments. An algorithm for finding out the exact layout for convex shapes has been developed by Nye [3] for unconstrained sheet width, which involve finding out the key vertices and using them to find out the utilization ratio, and numerically optimizing the piecewise continuous utilization function to get a global maximum. Another algorithm for finding out the exact layout for convex shapes has been developed by Joshi and Sudit [4] for constrained sheet width. Algorithms for finding out the exact layout for concave blanks have been proposed by Nye [3] and Vamanu and Nye [5] using the Minkowski sum to simulate rotation of one blank about other, and then numerically approximate the utilization function. Heuristic algorithms have been developed by Prasad and Somasundaram [6]. This paper uses the incremental rotation approach to find out the optimal utilization and then implements the probabilistic analysis to calculate the number of rejections and predict the total material utilization.

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A peculiar characteristic of all these algorithms developed is that they assume the metal sheet to be defect free and homogeneous. However, that is not the case in the industry. A pre-existing defect in the sheet, such as a local reduction in either thickness or strength, can have a large effect on the strain at failure. As an example, a tensile test specimen may have a defect region B that has a slightly lower load-carrying capacity than elsewhere. The initial defect can be a region that is thinner or that having a lower flow stress because of variations in grain size, orientations, or composition.

The stamping operations thus usually result in a certain number of rejected parts. They actually add to the material wastage and wastage of the effort put in the manufacturing of these rejected parts. Thus, it will always be helpful to an industry to use a system capable of predicting and minimizing these rejections at the sheet layout stage.

2. Material wastage

The wastage of material occurs for two reasons; the wastage due to layout of the blanks, and the wastage due to cracking, or failure during processing, e.g. stamping, forming, etc. Algorithms, as portrayed above, have been developed to minimize the former, however, none of them account for wastage due to cracking.

This paper attempts to obtain a blank layout to minimize the *total material wastage* accounting for the cracking of the blanks during processing.

To achieve this, it is postulated that when a defect on the sheet comes in the vicinity of a region on a blank that is highly strained during processing, failure is likely. The relation between the proximity of the region of maximum strain, the area of the defect and the probability of failure is assumed to be exponential:

$$\text{probability} = h\,\mathrm{e}^{(-1\times g\ \text{distance})} \tag{1}$$

The constants g and h may depend upon the material, defect sensitivity of the shape of the blank, the size of the defect, the severity of the defect, etc.

3. The algorithm for minimizing total wastage

3.1. Calculating the possible number of rejections probabilistically

Irrespective of blank geometry, let there be m regions of high strain on the blank. Let p_i be the probability (as stated in Section 2), such that the blank fails at i-th highly strained region. Then the probability of failure of the blank is found out by subtracting the probability of the blank not failing, from unity. Hence, one may write:

$$\text{pfailblank} = 1 - \prod_{i=1}^{m}(1 - p_i) \tag{2}$$

where pfailblank is the probability of failure in the blank encompassing a number of defects.

Now it is assumed that the *probabilities of failure*, found out using (1), of n different blanks laid out on the sheet are $p_1, p_2, p_3, \ldots, p_n$. To find out the number of rejections; let x be a random variable indicating the number of blanks failing. The probability density function for this random variable may be written as

x	$F(x)$
0	$(1-p_1)(1-p_2)(1-p_3)\cdots(1-p_n)$
1	$\{p_1(1-p_2)(1-p_3)\cdots(1-p_n)\}+\{(1-p_1)p_2(1-p_3)\cdots(1-p_n)\}+\cdots+\{(1-p_1)(1-p_2)(1-p_3)\cdots p_n\}$
2	$\{p_1p_2(1-p_3)\cdots(1-p_n)\}+\{p_1p_3(1-p_2)\cdots(1-p_n)\}+\cdots+{}^nC_2$ terms
$\vdots$	$\vdots$
n	$p_1p_2p_3\cdots p_n$

The mean or the mathematical expectation [7] of this function gives the mean rejections:

$$E(x) = \sum x\,F(x) \tag{3}$$

where $E(x)$ is the mean or the mathematical expectation.

3.2. Assumptions and approximations used

1. The defects are assumed to be randomly distributed over the area of the sheet.
2. The blank is assumed to be convex polygon. If not, it must be enclosed into a convex polygon. Any curves in the blank shape must be approximated as polygons.
3. The regions of maximum strain and the defects are approximated as points.
4. Function which relates the probability of failure with the distance between strained points and defects is assumed to be exponential.

4. Capabilities of the software

The software developed can nest the blanks so as to maximize the utilization of the material conventionally for a convex blank using an incremental rotation algorithm. Nesting in a single pass strip layout problem (one-dimensional nesting problem), as well as nesting in a two-dimensional sheet with finite length and width is possible. The sheet width is considered to be flexible and it recommends increase or decrease in sheet width if it assists the increase in material utilization.

Moreover, given the defect map for a metallic sheet, the software finds out the possible number of rejections at each step, and hence the total material utilization.

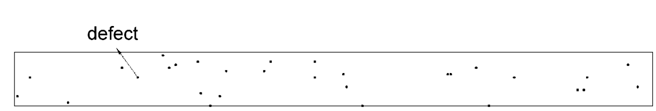

Fig. 1. Defect map of the sheet example 1.

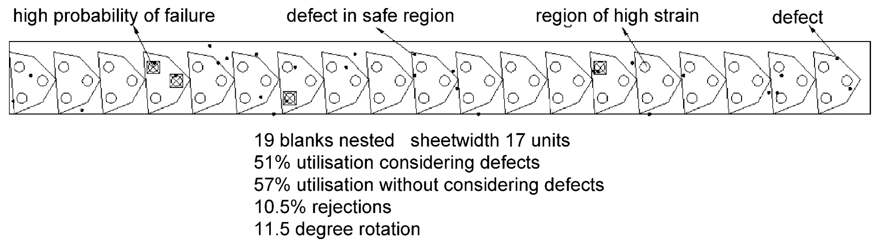

Fig. 2. Optimized for material utilization ignoring the defects on the sheet.

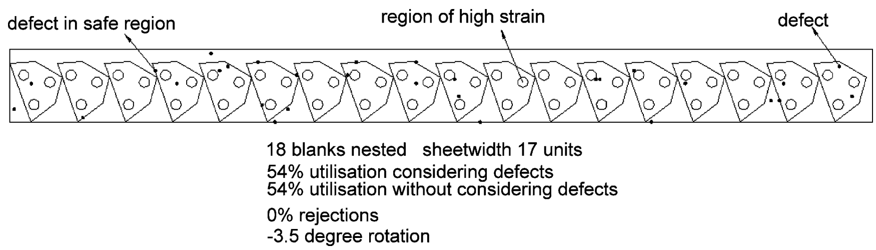

Fig. 3. Optimized for material utilization considering the defects on the sheet.

5. Results and discussion

The following examples are used to depict the usefulness of the software.

Problem definition: lay out the given shape of a blank on the given defect map of a sheet, such that the total material wastage is minimized.

This is viewed as a one-dimensional nesting problem to minimize total wastage wherein a single row of blank shapes is laid out on a strip of corresponding width, in the presence of defects in the sheet.

The blank used has the shape of an irregular pentagon (Fig. 2). The regions of high strain are marked on the blank by circles.

The defect map of the sheet is as shown in Fig. 1. In this example the calculation of material utilization is absolute, meaning that it is based on fixed values of sheet width and sheet length.

The percentage of rejection is calculated by considering the *probability of failure* of all blanks nested on the sheet. The values of probability of failure are substituted in Eq. (3) to predict the percentage of rejection.

Fig. 2 is the layout where utilization is maximized conventionally, i.e. without considering the rejections. But as it may be noted, some of the blanks nested are likely to fail during processing. Due to this, the material utilization reduces, and the layout proposed is no longer optimal for total material utilization for this particular sheet.

On the contrary, the layout in Fig. 3, although nesting fewer blanks, proves to be better as far as total material utilization is concerned. Here, none of the defects are close enough to the highly strained regions that might cause failures.

6. Conclusions

The foregoing describes a new concept for optimal layout of blanks on a metallic sheet to maximize the *total material utilization*. This will enable industries to significantly cut manufacturing costs using the layout which leads to a fewer number of rejections. As demonstrated in the examples, the layout which optimizes material utilization without considering the defects on the sheet may actually lead to a larger number of rejections and hence greater total wastage. A balanced layout optimized both for minimum rejections and maximum utilization, may lead to significant raw material, and hence cost saving.

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