面向21世纪高校双语教材

冲压成形工艺及模具设计

Stamping Forming Technology and Die Design

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·广州·

内容简介

“冲压成形工艺与模具设计”是一门专业基础课，它是高等学校模具设计与制造专业和塑性成形工艺与设备专业本科生必修课程，为后续的专业课程提供理论基础。本书是根据21世纪我国高等学校双语教学的需要所编写的第一本《冲压成形工艺及模具设计》的中、英双语对照教材，全书共分6章。第1章主要介绍板材冲压成形特点与冲压成形性能。第2章至第5章着重介绍冲裁、弯曲、拉深等成形工艺的基本理论、工艺特点、工艺计算、模具设计等。第6章对塑性成形其他一些方法，如局部成形、胀形、翻边、缩口、校形和旋压等进行了介绍。

本书可作为高等院校机械工程及自动化、材料成形与控制专业用或双语教学用教材，也可供有关工程技术人员参考。

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前　　言

“冲压成形工艺及模具设计”是一门专业基础课，它是高等学校机械工程及自动化、材料成形与控制专业本科生必修课程，为学生学习后续专业课程、进行专业毕业设计及今后工作奠定理论基础。

本书是根据21世纪我国高等学校双语教学的需要编写的第一本有关冲压成形工艺及模具设计的中、英双语对照教材，可作为高等院校机械工程及自动化、材料成形与控制专业用或双语教学用教材，也可供有关工程技术人员参考。

全书共分6章。第1章主要介绍板材冲压成形特点与冲压成形性能。第2章至第5章着重介绍冲裁、弯曲、拉深等成形工艺的基本理论、工艺特点、工艺计算、模具设计等。第6章对塑性成形的其他一些方法，如局部成形、胀形、翻边、缩口、校形和旋压等进行了介绍。

本双语教材由华南理工大学夏琴香副教授主编，梁佰祥参与了本教材第2章的编写工作，张赛军参与了本教材第4章的编写工作，本教材插图由梁佰祥、杨明辉、邓海萍等绘制，全书由华南理工大学张国强副教授及北京航空制造工程研究所陈适先研究员主审，在此深表感谢。

由于编著者水平有限，难免有不当之处，诚请读者提出宝贵意见。

编著者

2004年5月

Preface

Stamping Forming Technology and Die Design is a basic curriculum, and also a compulsory course for the undergraduates majoring in mechanical engineering and automatization, material forming and controlling. This course will establish the theoretical foundation for college students to study the further curriculums, to engage in the graduation design or to initiate the career in future.

This book is the first bilingual version in Chinese and English in our country about the *Stamping Forming Technology and Die Design* according to the demand of the bilingual teaching of high education in 21 century. It can be selected as the textbook or the bilingual textbook for the majors of the mechanical engineering and automatization, material forming and controlling, and also as the reference book for person specialized in these fields.

This book includes six chapters. Chapter one mainly introduces the characteristics of stamping and properties of sheet metal forming. Chapters two to five mainly introduce the basic theory, forming characteristic, technological calculation, and die design, etc. Chapter six introduces some other methods of plastic forming, such as local forming, bulging, flanging, necking, sizing and spinning.

This bilingual book was written by Associate Prof. Xia Qinxiang of South China University of Technology. Liang Baixiang and Zhang Saijun took part in the writing of Chapter two and Chapter four respectively. The illustration diagrams in this bilingual book were drawn by Liang Baixiang, Yang Minghui, and Deng Haiping, etc. This bilingual book was reviewed by Associate Prof. Zhang Guoqiang of South China University of Technology, and Prof. Sen. Eng. Chen Kuoxian of Beijing Aeronautical Manufacturing Technology Research Institute. To all the cooperators and many others, the author is pleased to express her gratitude.

Due to the limit of the author's knowledge, there would be some deficiency in the book, please put forward valuable suggestions.

Author,
May, 2004

目　录

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Introduction

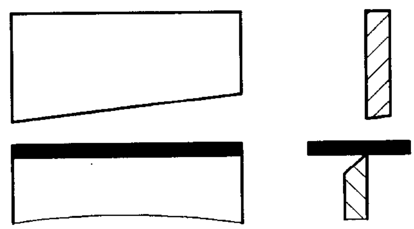
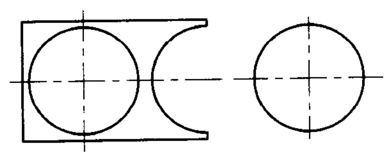
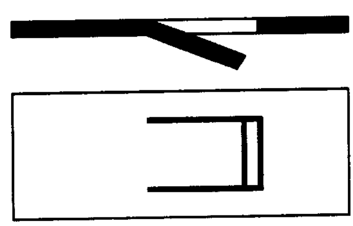
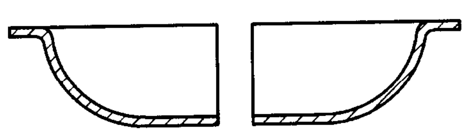
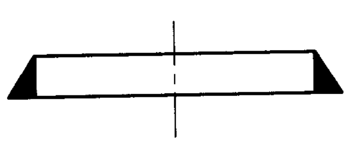
Metal processing is a branch of engineering science, which deals with the manufacturing of metallic parts and structures through the processes of plastic forming, machining, welding and casting. This book focuses on the stamping forming technology and its die design in metal processing. Stamping is mainly used in sheet plate forming, which can be used not only in metal forming, but also in non-metal forming. In stamping forming, under the action of dies, the inner force deforming the plate occurs in the plate. When the inner force reaches a certain degree, the corresponding plastic deformation occurs in the blank or in some region of the blank. Therefore the part with certain shape, size and characteristic is produced.

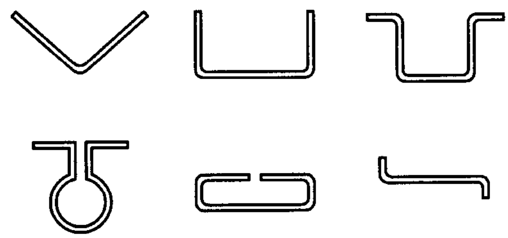
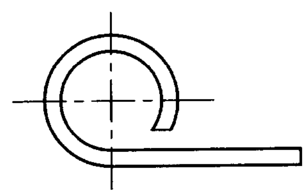
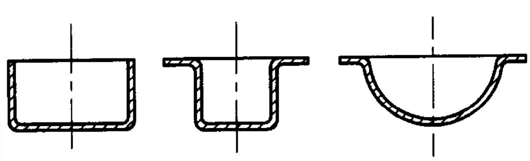
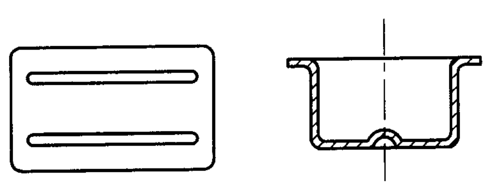
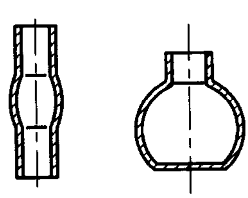
Stamping is carried out by dies and press, and has a high productivity. Mechanization and automatization for stamping can be realized conveniently owing to its easy operation. Because the stamping part is produced by dies, it can be used to produce the complex part that may be manufactured with difficulty by other processes. The stamping part can be used generally without further machining. Usually, stamping process can be done without heating. Therefore, not only does it save material but also energy. Moreover, the stamping part has the characteristics of light weight and high rigidity.

Stamping processes vary with the shape, the size and the accuracy demands, the output of the part and the material. It can be classified into two categories: cutting process and forming process. The objective of cutting process is to separate the part from blank along a given contour line in stamping. The surface quality of the cross-section of the separated part must meet a certain demand. In forming processes, such as bending, deep drawing, local forming, bulging, flanging, necking, sizing and spinning, plastic deformation occurs in the blank without fracture and wrinkle, and the part with the required shape and dimensional accuracy is produced.

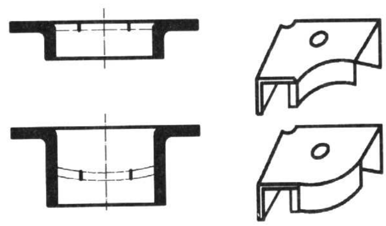
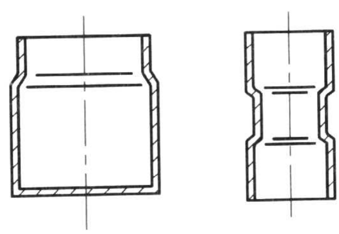
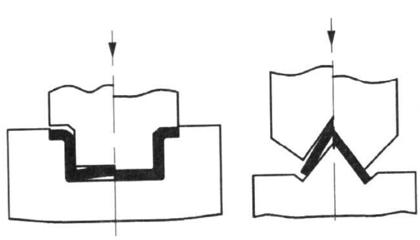
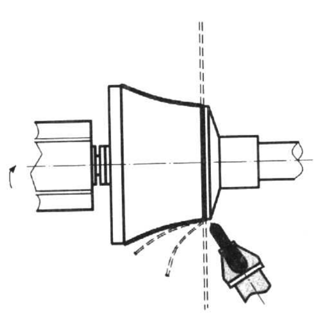
The stamping processes widely used are listed in the following table.

Widely used stamping processes

Process		Diagram	Characteristics
Cutting	Shearing		Shear the plate into strip or piece
	Blanking		Separate the blank along a closed outline
	Lancing		Partly separate the blank along a unclosed outline, bending occurs at the separated part
	Parting		Separate various work-piece produced by stamping into two or more parts
	Shaving		A layer of thin chip is shaved along the external side or the inner hole, to improve size accuracy and smoothness of the cross-section of shearing

Process		Diagram	Characteristics
Forming	Bending		Press the sheet metal into various angles, curvatures and shapes
	Curling		Bend ending portion of the plate into nearly closed circle
	Deep drawing		Produce an opened hollow part with punch and die
	Local forming		Manufacture various convex or concave on the surface of the plate or part
	Bulging		Expand a hollow or tubular blank into a curved-surface part

Contd.

Process		Diagram	Characteristics
Forming	Flanging		Press the edge of the hole or the external edge of the workpiece into vertical straight wall
	Necking		Decrease the end or middle diameter of the hollow or tubular-shaped part
	Sizing		Finish the deformed workpiece into the accurate shape and size
	Spinning		Form an axis-symmetrical hollow part by means of roller feeding and spindle rotational movements

Chapter 1 Characteristics of Stamping and Properties of Sheet Metal Forming

Stamping is a kind of plastic forming process in which a part is produced by means of the plastic forming of the material under the action of a die. Stamping is usually carried out under cold state, so it is also called cold stamping. Heat stamping is used only when the blank thickness is greater than 8～100mm. The blank material for stamping is usually in the form of sheet or strip, and therefore it is also called sheet metal forming. Some non-metal sheets (such as plywood, mica sheet, asbestos, leather) can also be formed by stamping.

Stamping is widely used in various fields of the metalworking industry, and it plays a crucial role in the industries for manufacturing automobiles, instruments, military parts and household electrical appliances, etc.

The process, equipment and die are the three foundational problems that needed to be studied in stamping.

The characteristics of the sheet metal forming are as follows:

(1) High material utilization.

(2) Capacity to produce thin-walled parts of complex shape.

(3) Good interchangeability between stamping parts due to precision in shape and dimension.

(4) Parts with lightweight, high-strength and fine rigidity can be obtained.

(5) High productivity, easy to operate and to realize mechanization and automatization.

The manufacture of the stamping die is costly, and therefore it only fits to mass production. For the manufacture of products in small batch and rich variety, the simple stamping die and the new equipment such as a stamping machining center, are usually adopted to meet the market demands.

The materials for sheet metal stamping include mild steel, copper, aluminum, magnesium alloy and high-plasticity alloy-steel, etc.

Stamping equipment includes plate shear and punching press. The former shears plate into strips with a definite width, which would be pressed later. The later can be used both in shearing and forming.

1.1 Characteristics of stamping forming

There are various processes of stamping forming with different working patterns and names. But these processes are similar to each other in plastic deformation. There are following conspicuous characteristics in stamping:

(1) The force per unit area perpendicular to the blank surface is not large but is enough to cause the material plastic deformation. It is much less than the inner stresses on the plate plane directions. In most cases stamping forming can be treated approximately as that of the plane stress state to simplify vastly the theoretical analysis and the calculation of the process parameters.

(2) Due to the small relative thickness, the anti-instability capability of the blank is weak under compressive stress. As a result, the stamping process is difficult to proceed successfully without using the anti-instability device (such as blank holder). Therefore the varieties of the stamping processes dominated by tensile stress are more than those dominated by compressive stress.

(3) During stamping forming, the inner stress of the blank is equal to or sometimes less than the yield stress of the material. In this point, the stamping is different from the bulk forming. During stamping forming, the influence of the hydrostatic pressure of the stress state in the deformation zone to the forming limit and the deformation resistance is not so important as to the bulk forming. In some circumstances, such influence may be neglected. Even in the case when this influence should be considered, the treating method is also different from that of bulk forming.

(4) In stamping forming, the restrain action of the die to the blank is not severe as in the case of the bulk forming (such as die forging). In bulk forming, the constraint forming is proceeded by the die with exactly the same shape of the part. Whereas in stamping, in most cases, the blank has a certain degree of freedom, only one surface of the blank contacts with the die. In some extra cases, such as the forming of the suspended region of sphere or cone, and curling at the end of tube, neither sides of the blank on the deforming zone contact with the die. The deformation in these regions are caused and controlled by the die applying an external force to its adjacent area.

Due to the characteristics of stamping deformation and mechanics mentioned above, the stamping technique is different from the bulk metal forming:

(1) The importance of the strength and rigidity of the die in stamping forming is less than that in bulk forming because the blank can be formed without applying large pressure per unit area on its surface. Instead, the techniques of the simple die and the pneumatic and hydraulic forming are developed.

(2) Due to the plane stress or simple strain state in comparison with bulk forming,

more research on deformation or force and power parameters has been done. Stamping forming can be performed by more resonable scientific methods. Based on the real time measurement and analysis on the sheet metal properties and stamping parameters, by means of computer and some modern testing apparatus, research on the intellectualized control of stamping process is also in proceeding.

(3) It is shown that there is a close relationship between stamping forming and raw material. The research on the properties of the stamping forming, that is, forming ability and shape stability, has become a key point in stamping technology. The research on the properties of the sheet metal stamping not only meets the need of the stamping technology development, but also enhances the manufacturing technique of iron and steel industry, and provides a reliable foundation for increasing sheet metal quality.

1.2 Categories of stamping forming

Many deformation processes can be done by stamping, the basic processes of the stamping can be divided into two kinds: cutting and forming.

Cutting is a shearing process that one part of the blank is cut from the other. It mainly includes blanking, punching, trimming, parting and shaving, where punching and blanking are the most widely used. Forming is a process that one part of the blank has some displacement from the other. It mainly includes deep drawing, bending, local forming, bulging, flanging, necking, sizing and spinning.

In substance, stamping forming is such that the plastic deformation occurs in the deformation zone of the stamping blank caused by the external force. The stress state and deformation characteristic of the deformation zone are the basic factors to decide the properties of the stamping forming. Based on the stress state and deformation characteristics of the deformation zone, the forming methods can be divided into several categories with the same forming properties and to be studied systematically.

The deformation zone in almost all types of stamping forming is in the plane stress state. Usually there is no force or only small force applied on the blank surface. When it is assumed that the stress perpendicular to the blank surface equals to zero, two principal stresses perpendicular to each other and act on the blank surface produce the plastic deformation of the material. Due to the small thickness of the blank, it is assumed approximately that the two principal stresses distribute uniformly along the thickness direction. Based on this analysis, the stress state and the deformation characteristics of the deformation zone in all kinds of stamping forming can be denoted by the points in the coordinates of the plane principal stresses (diagram of the stamping stress) and the coordinates of the corresponding plane principal strains (diagram of the stamping strain). The different points in the figures of the stamping stress and strain possess different stress state and deformation characteristics.

(1) When the deformation zone of the stamping blank is subjected to the plane tensile stresses, it can be divided into two cases, that is $\sigma_r > \sigma_\theta > 0$, $\sigma_t = 0$ and $\sigma_\theta > \sigma_r > 0$, $\sigma_t = 0$. In both cases, the stress with the maximum absolute value is always a tensile stress. These two cases are analyzed respectively as follows.

1) In the case that $\sigma_r > \sigma_\theta > 0$ and $\sigma_t = 0$, according to the integral theory, the relationships between stresses and strains are:

$$\frac{\varepsilon_r}{\sigma_r - \sigma_m} = \frac{\varepsilon_\theta}{\sigma_\theta - \sigma_m} = \frac{\varepsilon_t}{\sigma_t - \sigma_m} = k \tag{1.1}$$

where, ε_r, ε_θ and ε_t are the principal strains of the radial, tangential and thickness directions of the exial symmetrical stamping forming; σ_r, σ_θ and σ_t are the principal stresses of the radial, tangential and thickness directions of the axial symmetrical stamping forming; σ_m is the average stress, $\sigma_m = \frac{\sigma_r + \sigma_\theta + \sigma_t}{3}$; k is a constant.

In plane stress state, Equation 1.1 is rewritten as the following form:

$$\frac{3\varepsilon_r}{2\sigma_r - \sigma_\theta} = \frac{3\varepsilon_\theta}{2\sigma_\theta - \sigma_t} = \frac{3\varepsilon_t}{-(\sigma_r + \sigma_\theta)} = k \tag{1.2}$$

Since $\sigma_r > \sigma_\theta > 0$, so $2\sigma_r - \sigma_\theta > 0$ and $\varepsilon_r > 0$. It indicates that in plane stress state with two axial tensile stresses, if the tensile stress with the maximum absolute value is σ_r, the principal strain in this direction must be positive, that is, the deformation belongs to tensile forming.

In addition, because $\sigma_r > \sigma_\theta > 0$, therefore $-(\sigma_r + \sigma_\theta) < 0$ and $\varepsilon_t < 0$. The strain in the thickness direction of the blank ε_t is negative, that is, the deformation belongs to compressive forming, and the thickness decreases.

The deformation condition in the tangential direction depends on the values of σ_r and σ_θ. When $\sigma_r = 2\sigma_\theta$, $\varepsilon_\theta = 0$; when $\sigma_r > 2\sigma_\theta$, $\varepsilon_\theta < 0$; and when $\sigma_r < 2\sigma_\theta$, $\varepsilon_\theta > 0$.

The range of σ_θ is $\sigma_r \geqslant \sigma_\theta \geqslant 0$. In the equibiaxial tensile stress state $\sigma_r = \sigma_\theta$, according to Equation 1.2, $\varepsilon_r = \varepsilon_\theta > 0$ and $\varepsilon_t < 0$. In the uniaxial tensile stress state $\sigma_\theta = 0$, according to Equation 1.2, $\varepsilon_\theta = -\varepsilon_r/2$.

According to above analysis, it is known that this kind of deformation condition is in the region *AON* of the diagram of the stamping strain (see Fig.1.1), and in the region *GOH* of the diagram of the stamping stress (see Fig.1.2).

2) When $\sigma_\theta > \sigma_r > 0$ and $\sigma_t = 0$, according to Equation 1.2, $2\sigma_\theta > \sigma_r > 0$ and $\varepsilon_\theta > 0$. This result shows that for the plane stress state with two tensile stresses, when the absolute value of σ_θ is the maximum, the strain in this direction must be positive, that is, it must be in the state of tensile forming.

Also because $\sigma_\theta > \sigma_r > 0$, therefore $-(\sigma_\theta + \sigma_r) < 0$ and $\varepsilon_t < 0$. The strain in the thickness direction of the blank ε_t is negative, or in the state of compressive forming, and the thickness decreases.