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Preface

Since the reform and opening up more than 30 years ago, automobile industry, as the pillar industry of national economy in our country, has played an important role in improving the national standard of living and the quality of travel. The support from all fields has also contributed to the unprecedented development of our country's automobile industry. Two oil crises in 1970s made automobile industry face three big challenges: safety, energy saving and environmental protection. How to design and manufacture cars featured with energy saving and safety is the eternal pursuit goal of automobile industry in the future. The automobile in new ages not only needs to meet all kinds of collision safety laws and regulations such as front crash, side impact, offset collision, etc., but also has to reduce their own curb weight in order to get better fuel economy and achieve energy conservation and emission reduction. Studies have indicated that using new materials with high specific strength and good lightweight effect, such as high-strength steel, aluminum alloy, magnesium alloy and carbon fiber enhanced composite material, in automobile lightweight design and manufacture is the most effective way to achieve this goal. However, new materials such as high-strength steel plate, aluminum alloy and magnesium alloy all have disadvantage of poor toughness and plasticity, which has limited its application in car body, and new technology and new method therefore must be adopted to realize the design and manufacture. High-strength steel hot stamping technology emerges in this new situation.

Hot stamping technology is a new manufacturing technology combining the new material and new technology effectively to manufacture automobile parts. In hot stamping, the original steel plate of boron alloy steel is heated to a temperature of about 950 °C, then transferred to the water-cooling tools for stamping, quenching and forming, finally obtaining the lightweight components with satisfying performance. Hot stamping technology not only can solve the problem of poor formability, unmanageable springback and manufacture precision of high-strength steel sheet, but also can obviously improve the strength and hardness of steel during the forming and quenching process, and obtain ultrahigh-strength hot stamping car body structural parts with tensile strength as high as 1500 MPa. In addition, car body parts with hardness gradient composite properties based on the optimization of forming process can also effectively improve the characteristics of anti-collision and energy absorption, to improve the safety of the car. Based on the background of automobile lightweight and the advantages introduced above, high-strength steel hot stamping technology is booming in the global automotive body manufacturing industry. From the perspective of making China the world's biggest automobile producer with annual production up to 20 million in 2015, the development prospect of this technology is extremely broad, the corporate demand is also very big.

At present, the study of high-strength steel hot stamping technology abroad is very mature. The hot stamping technology was used in the aviation industry such as United States NASA (National Aeronautics and Space Administration), and nuclear industry at the beginning of the last century. The hot stamping technology suitable for auto parts production was first developed by N. Jernverkin 1973, and opened up its industrialization tour in the 1990s. It has been gradually applied and popularized on a global scale in big companies such as BMW and Volvo. As the mature hot stamping technology has been strictly closed in China, it had to be researched and developed from the very beginning in China. The AMT (Advanced Manufacture of Technology) research team led by Prof. Ping Hu in Dalian University of Technology have been studying on the hot stamping technology for more than 10 years, starting from the research field of mechanics for manufacturing process, focusing on the establishment of basic mechanics theory and the constitutive equation and the finite element algorithm for hot stamping. They have developed the KMAS_HF hot stamping sheet forming software with independent intellectual property rights, being the first to break the foreign monopoly and successfully develop a complete set of hot stamping process database and complete sets of production line with completely independent intellectual property rights.

The related scientific research achievements have been published in journals at home and abroad under the premise of not leaking the core technology. The research results have also been successfully applied and demonstrated in the industry in Japan KOBELCO Steel Company, China's Chery Automobile Co., Ltd., FAW Technology Center, JiLin VAFT Lightweight Technology Co., Ltd., and other related units.

As the industry's first monograph that systematically introduces the hot stamping technology from aspects of experiment, theory, method, and industrial application, this book comprehensively introduces the developing situation, equipment and process mechanism of the hot stamping technology. This book mainly introduces the related basic theory about multi-field coupled relationship among heat, stress and phase transformation, the finite element simulation technology and the actual engineering application of hot stamping products in automotive lightweight, together with the theoretical background for sheet metal hot stamping technology and its engineering significance in the field of auto parts. The book also provides a useful reference for other new technology related temperature and phase transformation, such as aluminum–magnesium alloy hot stamping. We sincerely hope the book will be beneficial for advanced manufacturing engineers, automotive design engineers, and researchers in other related fields.

The latest achievements and progress of hot stamping technology in the last 5 years are included in this book, which is organized in ten chapters. The contents include the research achievements and patents of the author and the AMT group for years, and have referred to the related scientific papers published in recent years. Chapter 1 introduces the basic knowledge of sheet metal stamping, including the development of stamping technology, the core basic knowledge such as process, tools, press machine, the production process, as well as the basic requirement of stamping process for material property, which lays a foundation for the subsequent introduction of hot stamping technology. Chapter 2 provides a systematic and concise introduction about the high-strength steel hot stamping technology and the main single equipment technology based on mass production line to make the readers have a macrolevel understanding of the technology. Chapter 3 expounds the process factors that affect the performance of high-strength steel and the original results of process optimization by authors' team in recent years. It also puts emphasis on illustrating the process mechanism to produce auto body parts with tailored properties. Chapter 4 mainly elaborates the hot stamping mechanical theory and constitutive equation for high-strength steel plate from a phenomenological level. Through experiments and theoretical analysis, quantitative research on multi-field coupling heat, stress, and phase transformations in hot stamping process is introduced, together with the stress–strain relationship derived from the law of mixture, and the hot stamping constitutive model of total strain theory and incremental theory, which have established the basic mechanics theory of hot stamping based on phenomenological significance. Chapter 5 establishes the single crystal and polycrystalline finite deformation constitutive integration algorithm under the condition of variable temperature based on the finite element algorithm by taking elastic–plastic deformation gradient and stress as basic variables. Combined with the thermal tensile curves, numerical simulation and experimental verification under thermal coupling are carried out. Chapter 6 focuses on the heat transfer theory in hot stamping process, including the mixed heat transfer theory between blank-tools and tools-channel in the process of transfer, punching, and quenching. The heat transfer coefficient between blank-tools and tools-channel is measured by inverse calculation and experiments. The factors such as high-temperature oxidation and the steel blank surface roughness are also studied in this chapter. Chapter 7 discusses the factors influencing the plasticity and deformation resistance of hot stamping materials, and establishes the high-temperature material constitutive model, which is suitable for multi-field coupling analysis, based on high-temperature material mechanics performance. Combined with the first set high-temperature forming limit TFLD test equipment developed independently in China, the 3D forming limit surface 3D-TFLD suitable for high-temperature formability prediction is obtained. In Chap. 8, the high-strength steel hot stamping FEM simulation algorithm is discussed from the four key problems of numerical simulation: the discussion of the variational equation in temperature field modeling and simulation, cell division, transient spatial domain, and discrete time domain. Meanwhile the fundamental equation and the solving method of the hot stamping phase transformation are analyzed and described. Based on the hot stamping multi-field coupling numerical simulation needs, this paper expounds the static explicit algorithm and dynamic explicit algorithm. Chapter 9 mainly introduces the application of hot stamping components and hardness gradient parts in lightweight car body. According to practical engineering, the hot stamping technology is applied to the typical body bearing parts such as door anti-collision beam, side wall, body beam frame, and the school bus pillars. And the application and optimization of typical body structures such as B Pillar are conducted with the hardness gradient composite properties of hot stamping. Chapter 10 mainly introduces the key technologies involving tool optimization design and manufacture in hot stamping technology. It also analyzes the fatigue and life of hot stamping die.

The relevant research work in this book is strongly supported by projects such as the Key Project of the National Natural Science Foundation of China, "973" National Basic Research Project of China and "04" Great Project of the Ministry of Industrialization and Information of China. After years of interdisciplinary collaboration research, from scientific theory to process practice, from the scientific problems to product research and development, the systemic research progress has been made. To promote the new technology of hot stamping automotive components manufacturing combining new material, new process and new equipment and to guide the innovation and development of auto parts manufacturing industry and then provide a new train of thought for the design and development of new cars are the purpose and motivation for the author to write the book. Errors are inevitable in this book due to the continuous development of hot stamping technology and the limitations of the author. Any comments from readers will be appreciated.

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In addition, Science Press has done a lot of productive work in editing the manuscript, we sincerely thank all the people and units who have made contribution to the publication of the book.

Contents

Chapter 1
The Basis of Sheet Metal Forming Technology

Metal pressure processing, also known as metal plastic working, is a kind of manufacturing method, which makes use of metal plastic deformation caused under external force to obtain raw materials, blanks, or components with a certain shape, size, and mechanical property.

Stamping is a kind of manufacturing technology that deforms sheet metal in the stamping tool by the deformation force supplied by the power of regular or special stamping equipment to obtain product components with certain shape, size, and mechanical property. Sheet metal, stamping tool, and stamping equipment are three major factors for stamping.

Along with the new compulsive policy about front impact, side impact, and emissions in automotive field, the automobile body parts made of thin and high strength sheet metal blanks have become the main trend of automobile industry. But for cold stamping technology, thinning and high strength are the double factors to worsen formability, which will make it easy to craze and produce excess springback in the forming process for body parts that affect the assembly of car's body subsequently. Especially, when the steel strength is higher than 1000 MPa, the traditional cold stamping technology is difficult to produce autobody parts with relatively complex structure and shape. To solve this problem, the hot stamping technology [2] arises at the historic moment.

Stamping can be divided into cold stamping and hot stamping according to the working temperature. The former is commonly used for metal sheet stamping at room temperature while the latter is suitable to process a kind of sheet which has high resistance to deformation and low plasticity.

Hot stamping, also called hot forming [1, 4, 5], is a plate processing technology that combines heat treatment process and cold stamping technology of sheet metal, aims at producing complex stamping parts with strength greater than 1000 MPa. For parts that have relatively complex shape and cannot be formed in one (direct) hot stamping, however, need an additional cold stamping before the hot stamping process. Thus, it is necessary to know the basic knowledge of cold stamping in consideration of the inheritance of hot stamping for cold stamping.

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1.1 The Development of Stamping Technology

Plastic working is a kind of metal processing method that has already existed in ancient times. The ancients struck the preformed metal blocks with hammers to make necessary tools, such as food containers and hunting forks. In China, the application of metal plastic working method can be traced back to 4000 years ago. At that time, forging was the main processing method, including cold forging and hot forging. Besides, there were some other processing methods applied, such as foil stacking forging, wire drawing, sheet metal forming, and stamping. The products made through plastic working method include weapons, production tools, daily necessities, leisure goods, etc. [3].

Nowadays, sheet metal forming is experiencing a fully automatic mass production in the field of automotive industry, household commodity, beverage cans, and other industries, while ancient sheet metal forming is made using hammer and anvil for piece production. Figure 1.1 shows the ancient sheet metal forming process: extension, thickening, projection, and hollowing. The wall thickness of the unearthed copper pottery of Yan State in late Spring and Autumn period (from the fifth century B.C to the sixth century B.C) is only 1–2 mm, which was excavated in Beixingbao, Huailai, Hebei province, China. The copper pottery is consisted of two

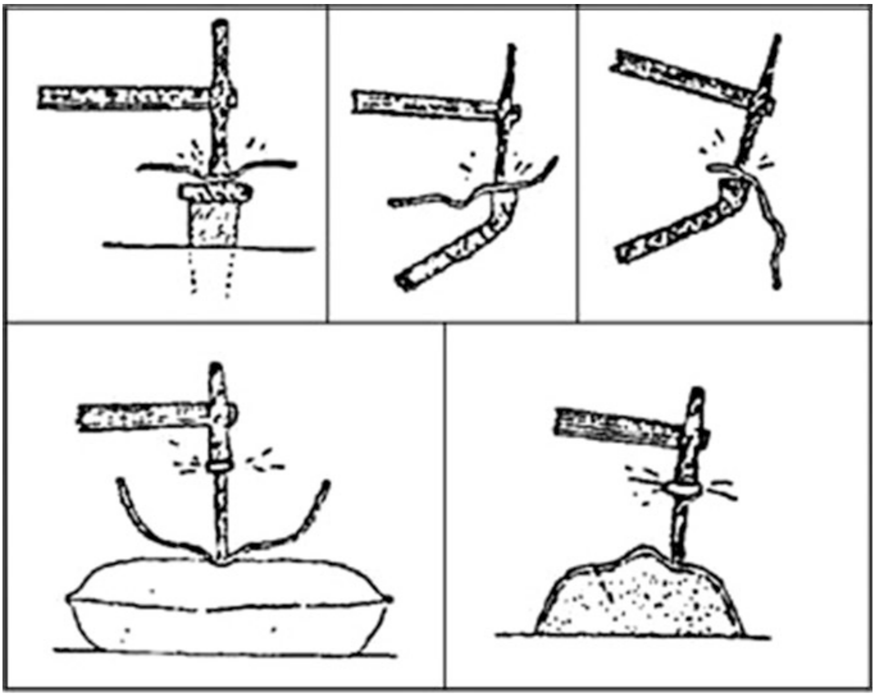

Fig. 1.1 Ancient sheet metal forming process

parts, the superstructure and infrastructure, which is hammer-shaped separately and then combines together in crimping snapped way.

It is generally considered that stamping era began during the European Industrial Revolution about 200 years ago. At that time, the development of modern iron technology contributed to the emergence of stamping machines. It means that the structure of the original machine that is controlled first by hands and then by feet (commonly known as pedaled machine) has changed. New stamping machine moves up and down, and forms products directly by feeding raw materials into the stamping tool installed in the middle of punching machine.

Subsequently, the world witnessed an era of great changes that the car originated in Europe crossed over the Atlantic. It brought a great convenience to Americans who used to be on horseback in the wilderness. However, the price was a problem in the process of car popularization. No matter how hard they tried, they could not afford to buy a car with such a high price, which led to the reduction of its value in use. As a result, using stamping to produce automotive parts became popular because of its contribution to lower the production cost. In the modern society, 60–65 % of car parts are made by stamping. In other words, the car can be described as the outcome of stamping. Stamping is proved to be the best way of mass production especially in this society where car is becoming more and more popular.

In the twentieth century, stamping technology has experienced five stages in developed countries [11].

Stage I: Before 1950s, the stamping line was composed of a double-action drawing press and several single-action drawing presses, feeding and unloading by hands, which caused the low production efficiency, poor security environment, and poor product quality.

Stage II: In the 1960s, the stamping line was still composed of a double-action drawing press and several single-action drawing presses. However, each press was equipped with an unloading robot hand in order to reduce the manual labor and the number of operators.

Stage III: In the 1970s, the automatic stamping line was established and could be operated only by one or two persons. This automatic stamping production was composed of several presses which were equipped with unstacking devices, feeding—unloading robots, middle turns-over or transmission mechanisms, and electronic control systems.

Stage IV: In the 1980s, owing to the emergence of multi-station presses, a double-action drawing press and a multi-station press were used for composing a stamping line. The main plywood of the multi-station press penetrated the mold area of the double-action press, while certain turns-over structures were equipped between the double-action press and the multi-station press to complete the transfer of the workpieces.

Stage V: Since the 1990s, with the advent of numerical controlled (NC) hydraulic cushion, the double-action drawing press was no more used as the leading equipment of stamping lines. Instead, hydraulic cushion was installed into the first station of the large multi-station press, which made this press form a flexible production unit independently. The large multi-station press equipped with such a NC hydraulic cushion as to produce flexibly becomes the development direction of large automobile cover stampings. Besides, it represents the most advanced technology level of stamping, and is also the most advanced stage of large automotive cover stamping development.

At present, China has become a big country of manufacturing and consumption. The metal plastic forming industry has also been developed rapidly [6] in China that the yearly output value has increased by 30 % on average during the period of 2001–2007. Metal forming industry involved in the whole manufacturing industry, the representative industry including [10] automobile, motorcycle, household refrigerators, washing machines and other household appliances, micro computers, integrated circuit, and mobile phones, among which cars, trucks, and buses are the main products in auto industry.

Automobile industry is the pillar industry of national economy in many countries with developed industry or emerging industrialization. In a car, the amount of sheet metal parts takes up more than 75 % of the total number of parts. In Japan, a country with developed automobile industry, the sales of automobile sheet metal parts account for 68 % of total sales in sheet metal industry, implying that the automobile sheet metal parts play an important role in the sheet metal industry, also declaring that the sheet metal forming technology plays an important role in a nation's industrial development. Since the twenty-first century, China's auto industry has developed thriftily and gradually into line with the international community, which has directly led to the progress of sheet metal forming technology and the plastic processing industry [8].

1.2 The Basics of Sheet Metal Forming

1.2.1 The Process of Traditional Cold Stamping

Stamping is a pressure processing method that puts pressure on the sheets or profiles at room temperature using stamping tools to produce plastic deformation or separation and then obtain parts with certain shape, size, and performance. The application range of stamping technology is so wide that it may not only process sheet metal and bar metal, but also a variety of nonmetallic materials. Since the process is usually carried out at room temperature, it is also called cold stamping.

The traditional cold stamping process of sheet metal is completed using stamping tools and stamping equipment. Compared with other processing methods, it has the following characteristics:

(1) The workpieces with complex shape, such as the shell parts, can be obtained by cold stamping method, which can be hardly formed by other machine processing methods;
(2) The dimensional accuracy of cold stamping is determined by the stamping tools. Therefore, it has the advantages of dimensional stability and good interchangeability;

(3) Because of its simple operation and low labor intensity, it is easy to realize mechanization, automation, and high productivity;
(4) Because of its high material utilization ratio, and its workpieces with light weight, good rigidity, high strength, and low energy consumption, the cost of the workpiece is rather low;
(5) The structure of the stamping tool used in the stamping process is relatively complex and the stamping tool has a long production cycle and high cost. So the stamping process is mainly used for mass production, and its application for single-piece and small batch production is subject to the restrictions. Nevertheless in recent years, the development of simple dies, combination dies, and zinc-based alloy dies offers the opportunity to the use of stamping process in single-piece and small batch production.

There are many different types of stamping process to meet the requirements on the shape, size, internal and external quality, and amount of workpieces. Generally, a multi-channel stamping process is needed for a stamping part. Due to the variety of shape, size, precision, production volume, and raw materials, there are also different processing methods which are used in cold stamping. To sum up, it can be divided roughly into separating process and shaping process.

Separating process is a stamping process through which the sheet can be separated by a certain contour to obtain stampings (also known as blankings) with certain shape, size, and cut surface quality. It includes blanking, piercing, incision, slice, and other processes.

Shaping process is a stamping process in which plastic deformation is produced under the condition of no material cracking and then the stamping parts with a certain shape, size, and precision are obtained. It includes bending, deep drawing, flanging, distortion, bulging, necking, etc.

1.2.2 The Cold Stamping Tool

Stamping tool is an important equipment in stamping production and is a kind of technology-intensive product. The quality, productivity, and production costs of stampings are directly related to the stamping tool design and manufacture. The level of stamping tool design and manufacture is one of the most important symbols to measure a country's level of manufacturing. It largely determines the quality and efficiency of products and the developmental capability of new products.

The type of stamping parts is varied with the type of stamping die. For the convenience of study, the stamping die is classified according to different characteristics. The following classifications are generally adopted:

(1) According to stamping process, it can be divided into blanking dies, bending dies, drawing dies, forming dies, etc.;
(2) According to the combination of process, it can be divided into single-process mode, composite mold, continuous mold, etc.

(3) According to the orientation mode of the upper and lower die, it can be divided into non-oriented opening dies, oriented guide plate dies, oriented guide pillar dies, etc.
(4) According to the way of guide pin or position, it can be divided into fixed guide pin die, movable guide pin die, pilot pin oriented die, side blade oriented die, etc.

The die can be also divided into fine blanking die and ordinary blanking die based on the size, quality, and precision of blanking. In addition, the die is also divided into small die, medium die, and large die based on the size of the die. Sometimes the die can be classified according to the type of punching machine, feeding method, and reclaiming method.

The kind of stamping methods determines the type and working conditions of relevant dies, and the requirements of die material. The blanking die is mainly used for the cutting of various sheet metals. Its edge is suffered from strong friction and impacted in the working process, so the materials with high wearing resistance, impact toughness and fatigue resistance are required for its working parts. The bending die is mainly used for the bending of the sheet metal, which has low workload and some friction. Thus the materials with high wearing resistance and fracture resistance are required for its working parts. The drawing die is mainly used for deep drawing of the sheet metal. The working stress is not very high, but its entrance has to withstand strong friction. Thus the materials with high hardness and wearing resistance are required for its working parts and the surface roughness of cavity die should be relatively small.

The selection of die material not only concerns the life of the die, but also directly influences the cost of die manufacture. Therefore, it is an important task in the process of die design. In the stamping process, the die has to withstand shock load and continuous work, which makes its punch and matrix work under great pressure and intense friction in poor working conditions. Therefore, the selection of die material should follow the following principles: (1) according to the type of the die and working conditions, the selection of materials has to meet the requirements, such as high strength, hardness, wearing resistance, impact resistance, fatigue resistance, etc.; (2) the selection of the materials is made according to press materials and production quantities of stampings; (3) to meet the processing requirements, the materials should have good processing performance to ease of machining, good harden ability, and low heat treatment deformation; (4) the materials should meet the economical requirements.

After the design of stamping die, the die's manufacturing is also an important process. Nowadays, the international mold and die manufacturing industry is seeking for product specialization and manufacturing digitization, while the mold and die manufacturing enterprises are also gradually turned to the develop direction of specialization, such as mold factory of Volkswagen, mold factory of Audi company, SCHULLER, Italy COMAU, American AUTODIE, SECKLY, mold factory of TOYOTA, Japan Fuji and Hyundai auto mold center, etc. Some of them are specialized in manufacturing dies for the overall side surrounding parts, dies of four doors, while some are specialized in dies of floor and structural parts. All the dies are moving to the direction of multi-stage, automotive, and progressive. In the meantime, the 3D entity design is widely used in die manufacturing, and the three-dimensional DL figure transferred from two-dimensional DL figure can be directly used in FM analysis and the CNC programming, realizing 100 % CAE analysis. The 3D parametric design technology applied to the tool design can realize the design of dies for different thickness sheet metal forming.

In China, mold was first listed in the catalogue of mechanical and electronic products mold in 1987 when the total GDP in mold industry reached 3 billion RMB. By 2004, the mold output value in China reached 53 billion RMB, ranking the third in the world. The total output value of 15 mold companies such as FAW mold manufacturing co., LTD. and Tianjin automobile mold co., LTD. became more than 1.5 billion RMB in 2004, and the national total sales of mold industry in 2005 is as high as 61 billion RMB. At present, the mold enterprise for auto body has spread throughout the country, and 50 of them have formed a certain scale, while half have an annual production of 10–50 million RMB.

1.2.3 Stamping Press

Stamping press is a kind of general equipment with exquisite structure and can drive dies to form steel sheet. To processing part, it makes the metal to plastically deform and fracture by applying powerful pressure, which can be widely used in cutting, punching, blanking, bending, riveting, and forming process. Stamping press, also called press machine, is characterized with widely used and high production efficiency, etc.

There are two kinds of commonly used stamping press, the mechanical press and hydraulic press. When the mechanical press works, the big belt pulley is driven by motor through the triangle belt, then drive the slider-crank mechanism straight up and down through gear pair and clutch. When the forging work is completed, the slider moves upward, clutch releases automatically and the automatic device on crank shaft connects at the same time, making the slider stop near the top dead center. Mechanical press can be divided into crank press and friction press according to the type of driven slider mechanisms, or be divided into single-action press and double-action press according to the number of slider blocks, or be divided into frame press and straight side press according to the structure of machine tool bed, or be divided into general press and high speed press according to the degree of automation, etc.

And hydraulic press [7] is a machine used to transfer energy and achieve various techniques. It is produced according to the PASCAL's principle and takes liquid as working medium. Hydraulic press usually consists of the main engine, power system, and the hydraulic control system. According to the working medium, the hydraulic press can be divided into oil hydraulic press and water press. The working principles and features of commonly used stamping presses are shown in Table 1.1.

Table 1.1 Working principles and features of commonly used hot stamping equipments

Type	Device	Working principle	Feature
Mechanical press	Friction press	It transmits the motion by using the friction engagement between the flywheel and the friction disks, and works under the function of the screw and the nut with the principle of relative motion	The structure is simple. Only sliding between the flywheel and the disks will occur under the condition of overload. However, the abrasion to the rim of the flywheel is serious and the productivity is low. It is suitable for middle and small workpiece stamping, especially for the procedures of calibration, coining and forming, etc.
	Crank press	It works with the use of crank-link mechanism. The crankshaft is driven by the electric motor with the pulleys and gear to make the slide reciprocate in a straight line through the connecting rod. Crank press is divided into eccentric press and knuckle-joint press. The main difference between the two presses lies in the spindle, as the former has an eccentric shaft and the latter has a crankshaft. Eccentric presses are generally open presses, while knuckle-joint presses are divided into open and close presses	The productivity is high, so it is applicable to all kinds of stamping processes
	High speed press	It is a kind of special crank press developed due to the need of mass stamping production. The working principle of this press is the same as that of general crank press. But relatively speaking, its rigidity, accuracy, stroke times are all higher. Its stroke times are generally 5–9 times than that of the general crank press. The application of high speed press must be equipped with auxiliary devices (like automatic feeding device, safety testing device, etc.) to achieve high speed machining for stamping	The productivity is very high; it is suitable for mass production. Multi-station progressive die is generally used
Hydraulic press	Oil hydraulic press and Water press	Using Pascal's principle and taking water or oil as working medium, hydraulic press works with the transmission of static pressure to make the slide travel up and down	The pressure is high and static, but the productivity is low. It is suitable for the forming processes such as drawing, extrusion, etc.

Furthermore, for the small batch production of flat sheet, it is generally machined by numerical control (NC) stepping press in order to reduce production cost, shorten production cycle, reduce labor intensity, and improve production efficiency. NC stepping press is a type of press which fulfills punching and nibbling on the blanks with NC technology, so it is an efficient and sophisticated single stamping device of sheet. Punching sheet is fixed on the platform, and then driven to move from left to right, up and down, and positioned according to the prescribed procedure. The molds are installed on the turret for automatic shifting, or installed on the die adapter for manual rapid shifting. The holes and parts are punched into different shapes and sizes with single punching or nibbling punching.

At present, the development of world's large stamping press are going to two directions, one is large and multi-station, the other is focusing on flexible production equipped with automation manipulator. In the recent 10 years, the press has contained many key technologies after continuous development as follows: fully automatic system for die changing, perfect automatic monitoring system, and good human–machine interface, high stroke frequency for high production efficiency and the necessary high precision for high-quality stamping parts. Nowadays, the automobile companies in United States, Japan, and German have equipped higher proportion of transfer press. In China, a majority of the production line is for single wire press and the character for key stamping equipment is large tonnage, large stroke, large table-board, large-tonnage air cushion and the slider air cushion, manipulator system for loading and unloading, high speed, high precision, automatic technology for die changing and function perfect touch screen monitor technology.

So far, the most advanced press adopts servo motor, the tonnage in a few years ago is up to 250 and 500 t, respectively, but now is up to 1000 t. Press of this type controlled by servo motor can realize the control of press speed and working stroke, has attracted attention of many famous automobile company, together with their bulk order. This press can further reduce the stamping process and improve the accuracy of parts, having obtained a much bigger application range. Combined with the application of the nitrogen cylinder, there must be a very broad developmental space for this kind of press.

1.2.4 The Production Process of Stampings

The general production process of stampings is shown in Fig. 1.2. Stamping technology includes stamping process design, die design, and die manufacture. Though the contents of the three aspects are different, they are interrelated, influenced, and interdependent. The basic contents and requirements of them are described in Table 1.2.

It should be pointed out that die design and manufacture must be taken into comprehensive consideration according to the actual situation of enterprise and products' production batch to find the optimal economical technology and

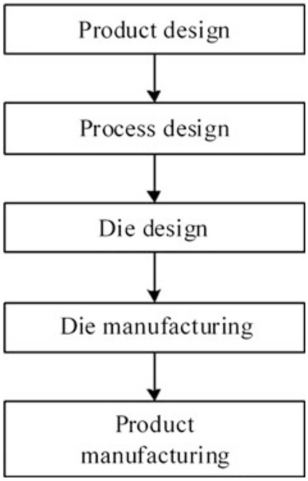

Fig. 1.2 Production process of stampings

Table 1.2 The basic contents and requirements of stamping forming

Item	Basic contents	Basic requirements
Process design	For a given product drawing, a reasonable process scheme (including the property and amount of processes, their sequence, their location mode and combination mode) should be made, according to its production batch, stamping equipment types and specifications, die manufacturing capacity and worker's level of technology. The process scheme should be based on the analysis of the stamping process of part drawing and the process calculation. At last, the stamping process card is obtained	(1) The raw materials should have high utilization rate, that is to say, low material consumption (2) According to the specific production conditions, the process scheme should be technologically advanced and feasible, and economically reasonable (3) Process combination mode and process sequence should comply with the stamping deformation law to ensure qualified workpieces will be produced through stamping (4) The scheme should have low process number and high production efficiency (5) The technological procedure should be made convenient for production organization and management
Die design	According to the stamping technological procedure, the overall structures of corresponding dies are calculated and then designed with the consideration of blank orientation, unloading, waste elimination, stamping tool manufacturing and maintenance convenience, safe and	(1) The structure and size parameters of stamping tools should guarantee the shape, size, and accuracy of the products by stamping should be in line with drawing's requirements (2) Simple structure, reasonable processing accuracy, manufacturing

(continued)

Table 1.2 (continued)

Item	Basic contents	Basic requirements
	reliable operation. After the calculation and design of structures, the assembly drawing and nonstandard part drawing should be plotted to ensure the implement of stamping process	and maintenance convenience, and low cost are required in the design process (3) The die should be firm and durable and satisfy the requirements of mass production (4) It is easy, safe, and reliable to operate the die with low labor intensity. (5) The preparation period of production should be shortened
Die manufacture	The die should be manufactured according to the demand on die structure, die material, size and geometrical accuracy, work characteristics, service life etc. During the process of die manufacturing, the characteristics of existing equipment, the machining method and assembly method should be considered to select an optimal processing scheme, and make out the reasonable die processing technological procedure	(1) To ensure the quality of products and the performance of die, the die should be made with high accuracy (2) The die should be manufactured with a long service life (3) The manufacturing cycle should be short (4) Low manufacturing cost is required

simultaneously guarantee product quality. Excessive pursuit of production efficiency, die accuracy, and its service life will inevitably lead to the increase of cost. However, only considering the reduction of cost and a shorter manufacturing period and ignoring die accuracy, its life will inevitably lead to a drop in quality.

1.3 Materials for Cold Stamping and Its Formability

1.3.1 Requirements on Materials for Cold Stamping

Materials used in stamping should not only meet the technical requirements for product design, but also meet the requirements of the stamping process and subsequent processing requirements (such as cutting, welding, electroplating, etc.). The basic requirements on materials in stamping process are concluded below:

(1) Formability

In order to improve the deformation and stamping parts quality, materials should have good formability. The formability of the material is closely related to its mechanical properties. Therefore, the materials should have good plasticity, small yield strength ratio, high elastic modulus, large normal anisotropic coefficient, and

Table 1.3 Specific requirements of different stamping procedures on the sheet performances

Procedure	Performance requirement
Blanking	Sufficient plasticity, and no cracking in punching; The hardness of materials should be lower than that of punch die
Bending	Sufficient plasticity, low yield limit, and high elastic modulus
Drawing	Good plasticity, low yield limit, large normal anisotropic coefficient, small yield strength ratio σ_s/σ_b, and small plane orientation

small plane orientation coefficient. Specific requirements of different stamping procedures on the sheet performances are shown in Table 1.3.

(2) Thickness tolerance

The thickness tolerance should comply with the national standard. A specific die clearance applies to the material with a specific thickness. Large thickness tolerance not only can directly affect the quality of the product, but also may cause the damage of die and punch.

(3) Surface quality

The surface of materials should be bright, smooth, no stratification, no mechanical damage, and no rusty spot, oxide skin and other attachments. Materials with good surface quality do not easily tend to crack and scratch the die surface during stamping; stamping parts with good surface quality can be manufactured.

1.3.2 The Formability of Materials

1. Concept of stamping formability

Just as other processing methods, stamping processing method is based on the material performance. The materials used in stamping processing must have a good stamping formability.

The stamping formability of the material is defined as the capacity of adapting itself to different stamping processing methods. Materials with good formability refer to its handling ease, high limited deformation and total limited deformation, high productivity, high-quality products, long stamping tool service life, etc. This shows that stamping formability is a comprehensive concept, which involves many factors. From the perspective of its contents, there are only two factors involved, forming limit and forming quality.

(1) Forming limit

The maximum deformation degree of the material achieved during the forming process is defined as forming limit. Coefficients of deformation limit are used to represent different forming limits in different forming process. Most stamping forming is conducted in a state of plane stress which ignores stress in the thickness direction, so it is not difficult to analyze the following phenomenon. In the interior of the deformation blank, excessive tensile stress will make part of it severely thinned, even cracked and scraped, and excessive pressure stress will make part of it lose stability and then wrinkle. Therefore, in order to improve the forming limit, the blank material requires better plasticity and stronger resistance to tension and compression.

In the stamping process, the deformation formed by tensile stress with maximum absolute value on the deformation region of the blank is called tensile deformation (such as bulging, flared, hole flanging, etc.). The deformation formed by compressive stress with maximum absolute value on the deformation region of the blank is called compression deformation (such as drawing, necking, etc.). Coefficients of deformation limit of tensile deformation mainly depend on material plasticity, while coefficients of deformation limit of compression deformation is usually affected by the carrying capacity of blank force transmission zone, and sometimes affected by instability and wrinkle of deformation zone or force transmission zone.

(2) Forming quality

The main quality indicators of the stamping parts are dimensional accuracy, thickness variation, surface quality, and the physical and mechanical properties of materials after forming. There are many different factors which influence the quality of stamping parts in different stamping processes.

The plastic deformation always accompanies with the elastic deformation in the deformation process of materials. Due to the elastic recovery resulting from loading, the size and shape of stamping parts deviate from the stamping tool, which affects their size and form accuracy. Therefore, it is very important to grasp the springback law to control the springback.

After pressing stamping, the thickness of blanks generally becomes thinner or thicker. The thickness thinning directly affects the strength and the use of stamping parts. Therefore, the maximum thinning should be defined if requests are made regarding the strength of stampings.

After plastic deformation, materials suffer from work hardening and residual stress caused by nonuniform deformation. The residual stress on materials causes changes in the size and shape of workpieces, and leads to the cracking of workpieces under severe conditions. All of these circumstances should be considered in the course of making stamping process.

The factors affecting the surface quality of workpieces are the surface state and grain size of raw materials, the condition of the stamping tool sticking to material and the abrasion of the stamping parts' surface by the stamping tool. The surface state of raw materials directly influences the surface quality of workpieces. When stretched, the steel plate with coarse grains forms the so-called "orange peel" (with rough surface). Stamping materials that are easily sticking to stamping tool will scratch the stamping parts and reduce stamping die life. In addition, the uneven die clearance and rough surfaces will also scratch the stamping parts.

2. Testing methods of sheet formability

The formability of sheet is measured by different test methods. These tests can be roughly divided into indirect and direct test. Indirect test methods include tensile test, shear test, hardness test, metallographic test, etc. In the indirect tests, the stress state and deformation characteristics of test samples are somewhat different from those of the actual stamping, so the results of these tests can only indirectly reflect the stamping performance of sheet metals. However, these tests can be conducted on general-purpose test equipments, so they are usually adopted to measure the formability. Direct test methods include repeated bending test, bulging performance tests and deep drawing performance test, etc. In such tests, the stress state and deformation characteristics of test samples are basically the same as those of actual stampings, so these direct tests can provide direct and reliable identification for the formability of certain types of stamping. But in these tests specialized test equipment or tooling are required. The following part is the introduction of tensile test, which is known as the most frequently used indirect test.

Tensile specimens which are cut from different positions and directions of the sheet are made according to the standard shown in Fig. 1.3. The specimens will be stretched by using a universal testing machine. According to the test results or by using the automatic recording devices, the stress and strain curve (or stretch curve) shown in Fig. 1.4 can be obtained.

The mechanical properties of sheet metal can be measured by the tensile test. The formability of sheet metal has a very close relationship with its mechanical properties, so its formability can be reflected by these properties from different perspectives. In general, the higher its strength is, the greater the force producing the same amount of deformation is. The higher its plasticity is, the greater the amount of limit deformation is. The higher its stiffness is, the greater the ability of resistance to instability and wrinkle is. Some essential mechanical properties are illustrated as follows:

(1) Total elongation δ and uniform elongation δ_b

δ represents the total elongation of the destroyed specimen in tensile test, called elongation for short. δ_b represents the uniform elongation when local concentration of deformation begins to generate in the tensile test (first appearing necking). δ_b is

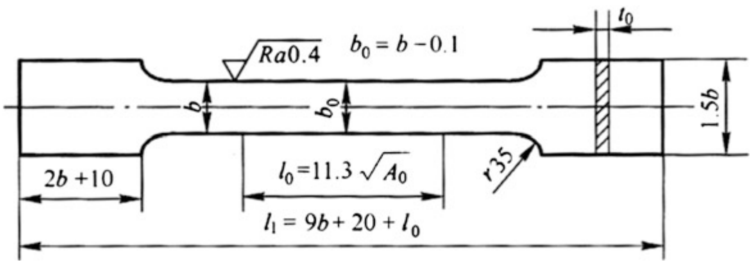

Fig. 1.3 Standard tensile specimen

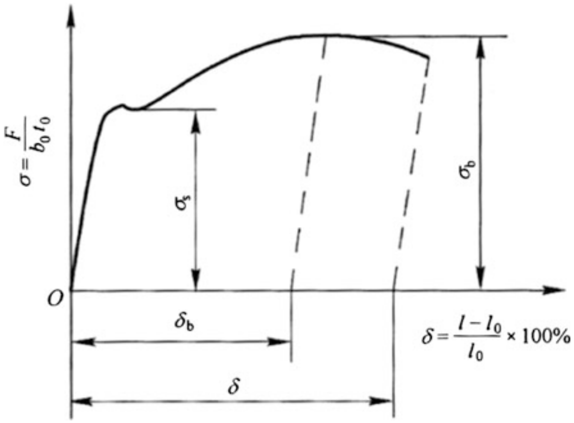

Fig. 1.4 Stress and strain curve

an indicator of the capacity of producing uniform or stable deformation. In general, sheet metal forming is carried out within the scope of uniform deformation, so δ_b affects the sheet metal forming more directly. In the process of tensile deformation, such as hole flanging, bulging, and other processes, the larger δ_b is, the greater the limit deformation is.

(2) Yield ratio (σ_s/σ_b)

σ_s/σ_b, called yield ratio, is the ratio of material yield limit to ultimate strength ratio. Small yield ratio means a big difference between σ_b and σ_s. The material with this yield ratio can withstand a large plastic deformation without rupture, which is beneficial to stamping forming.

In the process of the compression deformation, such as deep drawing, small yield ratio and low material yield point descend the tangential stress of the deformation zone, the trend of sheet metal to wrinkling and instability, and the binder force to prevent binder from wrinkling and frictional force. Thus the total deformation force and the force transmission zone loads are decreased. The higher the ultimate strength is, the greater the bearing capacity of the power transmission area is. In a word, the small yield ratio is in favor of improving the forming limit.

In the process of the tensile deformation, such as bulging, the small yield ratio which means a great difference between the tensile force in plastic forming and that in blank rupture makes the stability of plastic deformation ascend and the probabilities of blank cracking during drawing and accompanying waste products descend.

(3) Elastic modulus E

Elastic modulus is the stiffness index of the material. The greater the elastic modulus is, the stronger the ability of resisting compression and instability in forming is, and the smaller the elastic recovery is after unloading. This is helpful to improve the dimensional accuracy of parts.