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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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Contents