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“FORMING DIE DESIGN AND PRESS CAPACITY SELECTION FOR AUTOMOTIVE SHEET-METAL COMPONENTS: A REVIEW OF FORMING LOAD ESTIMATION, DIE MATERIALS, AND NUMERICAL METHODS”

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ABSTRACT

Sheet-metal forming is widely used in the automotive industry to produce components such as oil pans, body panels, covers, brackets, and structural parts with good dimensional repeatability and high production rates. The successful manufacture of such components depends on a properly designed forming die and on the selection of a press with sufficient capacity for the forming load, while the die itself must remain rigid enough to transfer that load without excessive deformation. However, forming loads are frequently estimated by simplified relations, press capacity is selected with uncertain allowances, and the structural behaviour of the die assembly is often assumed rather than verified. This review paper presents an assessment of published work and established engineering practice related to forming-die design for automotive sheet-metal components, with particular emphasis on forming-load estimation, press tonnage selection, die and punch materials, load transfer through the die assembly, and numerical methods such as finite element analysis for predicting forming behaviour and springback. Studies on deep drawing, springback prediction, tool clearance, lubrication, inverse finite element methods, and computational-intelligence approaches are examined. The review indicates that preliminary analytical estimates are valuable for press selection but must be supported by a design allowance and, where possible, by numerical simulation and experimental trials, and that few studies report press-capacity utilization together with the load path through the die assembly. Research gaps are identified, including limited validation of simplified load formulas for shallow formed components, scarce reporting of die-assembly structural checks, and limited use of material data specific to the sheet being formed. The findings are intended to support the development of reliable forming dies and rational press selection for automotive oil-pan manufacturing.

Key Words: Forming die; sheet-metal forming; automotive oil pan; forming load; press capacity; D2 tool steel; springback; finite element analysis; die design.

I. INTRODUCTION

Manufacturing processes determine the shape, dimensions, strength, and surface quality of mechanical products, and sheet-metal forming is among the most widely used processes in the automotive and general engineering industries. Sheet-metal components are produced by cutting, bending, drawing, stretching, punching, embossing, and forming, generally with the help of specially designed tools known as dies. The die controls the deformation of the sheet, and the quality of the formed component depends on the design, material, accuracy, stiffness, and working condition of the tooling [1], [2]. In the automotive sector, large numbers of sheet components are manufactured in this way, including body panels, covers, engine and transmission components, guards, and oil pans. An oil pan is a shallow container attached to the lower part of the engine or transmission housing that holds lubricating oil, and it must provide adequate

strength, accurate mounting locations, and a reliable sealing flange. It is typically formed from low-carbon steel sheet by pressing the sheet into a die cavity with a punch.

A forming die generally consists of a punch, a die block, and structural plates that locate and support the active components. The punch and die block contact the sheet directly and are subjected to repeated loading and wear, so they are commonly made from high-hardness tool steels such as D2, which offers high wear resistance and dimensional stability, whereas the top and base plates mainly provide structural support and load transfer and can be made from economical mild steel [6]. During operation, the press load is transferred from the press ram through the top plate and punch to the sheet, and the reaction passes through the die block and base plate to the press bed. For a die to function reliably, the press must be able to supply the required forming load with an adequate margin, and the tooling must carry the load without excessive deflection that would impair alignment between punch and die. The selection of press capacity is therefore a central step in die design, and it depends on an estimate of the forming force.

The forming load depends on the sheet material and thickness, the geometry of the component, friction between the sheet and tooling, the clearance between the punch and die, the blank-holder force, and the forming speed [1]–[4]. For preliminary design, simple analytical relations based on the deformed perimeter, sheet thickness, and a representative stress are widely used to estimate press tonnage, and a design allowance is added to cover variations in material properties, lubrication, and process conditions. More detailed estimates are obtained through finite element simulation, which can predict forming loads, thickness distribution, strain concentration, springback, and possible failure locations before tooling is manufactured, thereby reducing physical trials [7]–[10]. This paper reviews the literature on these topics, with the aim of identifying good practice for forming-die design and press selection for automotive sheet components such as oil pans, and of highlighting the gaps that remain.

II. PROBLEM IDENTIFICATION

The increasing demand for sheet-metal components in automotive and industrial applications requires forming dies that can produce parts with high dimensional accuracy, good surface quality, repeatability, and adequate structural strength. Forming a flat sheet into a three-dimensional shape such as an oil pan involves significant plastic deformation, and improper die geometry, insufficient die strength, unsuitable material selection, or excessive forming force can lead to defects such as wrinkling, tearing, excessive thinning, springback, dimensional variation, or damage to the die components. The press used for the operation must be large enough to deliver the required load without being overloaded, yet not so large that capital and operating costs are unnecessarily high.

A particular difficulty is that forming loads in practice are often estimated from simplified relations whose accuracy depends strongly on the assumed representative stress and on how the deformed perimeter is defined. For components with ribs, corner radii, flanges, and local contours, the actual forming perimeter and deformation mode differ from the idealized geometry. Allowances of different magnitude are applied by different designers, and the reported basis for these allowances is seldom documented. In addition, published studies on forming usually concentrate on the sheet, its formability, and springback, whereas the die assembly, including the top plate, base plate, and the path by which load reaches the press bed, receives comparatively little attention, even though its stiffness controls punch alignment.

Consequently, there is a need to consolidate the available knowledge on forming-load estimation, press capacity evaluation, die materials, and numerical prediction methods, and to identify where the existing evidence is insufficient for the design of dies for shallow automotive components such as oil pans. This review addresses that need.

III. RESEARCH OBJECTIVE

The main objective of this review paper is to critically examine published work and established practice related to the design of forming dies for automotive sheet-metal components and the selection of press capacity. The specific research objectives are as follows:

- To review forming-load estimation: Examine the analytical relations used to estimate forming force and press tonnage, and the factors that influence them.

- To evaluate press capacity selection: Review the use of design allowances, standard press ratings, and capacity utilization in selecting a press for a forming operation.
- To review die and punch materials: Compare the materials used for active forming components and for supporting plates, with emphasis on D2 tool steel and mild steel.
- To examine load transfer and structural integrity: Review how forming load is transferred through the press, die assembly, and press bed, and how die stiffness affects accuracy.
- To analyze numerical methods: Evaluate the use of finite element analysis for predicting forming load, thickness distribution, and springback, and the influence of numerical parameters.
- To assess process parameters: Examine the effect of clearance, lubrication, blank-holder force, and friction on forming quality.
- To review emerging approaches: Examine inverse finite element methods and computational-intelligence techniques used to support die design.
- To identify research gaps: Identify limitations in existing studies relevant to forming dies for shallow automotive components such as oil pans.

IV. LITERATURE REVIEW

The design of forming dies and the selection of presses are supported by a body of textbook knowledge and by research on sheet-metal forming, deep drawing, springback, and numerical simulation. The works reviewed below include standard references on metal forming and manufacturing and research papers published between 1998 and 2022. For each research study the scope, method, and principal findings are summarized as reported by the authors, and its relevance to forming-die design and press selection is highlighted.

Standard references on metal forming [1]–[4]. The textbooks of Hosford and Caddell, Altan and Tekkaya, Marciniak et al., and Kalpakjian and Schmid describe the mechanics of sheet forming, including the relation between sheet properties, tool geometry, friction, and forming load. They establish that the forming load of a sheet operation depends on the deformed perimeter or area, the sheet thickness, the flow stress of the material, and additional factors such as blank-holder force, friction, and draw depth. These references provide the basis for the simplified perimeter–thickness–stress estimates used in preliminary press selection, and they also make clear that such estimates are approximate and should be supported by an allowance and, for critical applications, by simulation or trials.

Ikumapayi et al. (2022) presented a review of the deep-drawing process and its applications in manufacturing [5]. The study explained that deep drawing transforms a flat sheet blank into a three-dimensional component without excessive failure or localized thinning, and it discussed applications in several industries, including automobile components and oil pans. Defects such as wrinkling, tearing, ironing, earing, and galling were considered, and the review emphasized that control of punch load, material deformation, friction, and forming conditions is necessary to obtain defect-free components. This study is directly relevant to oil-pan forming because it links the forming load and process variables to the quality of the formed part.

Lee and Yang (1998) investigated the numerical parameters that influence springback prediction in explicit finite element analysis of sheet-metal forming [7]. Springback was identified as a key factor affecting the quality of stamped parts, and the numerical factors were evaluated quantitatively using the Taguchi method, with explicit integration for the forming stage and implicit integration for the springback stage. The study showed that springback results can vary greatly with how numerical factors such as element size, punch velocity, contact penalty constant, and damping are set, so that a comprehensive assessment of numerical parameters is needed for reliable prediction.

Papeleux and Ponthot (2002) studied the finite element simulation of springback in sheet-metal forming, using a U-draw bending problem to examine the influence of physical and numerical parameters [8]. Parameters such as blank-

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holder force, friction, hardening behaviour, integration conditions, and constitutive modelling were considered. The study showed that springback prediction is sensitive to both material behaviour and numerical modelling conditions, which provides a basis for considering springback during die development and for modifying the die geometry when required.

Lei et al. (2001) investigated stainless-steel sheet forming using finite element analysis and compared the numerical results with experiments [9]. Bending and drawing operations were analysed with the MARC finite element code. The researchers observed that springback was influenced by the clearance between the punch and the workpiece and that lubrication conditions were important in square-cup deep drawing because contact and friction between the sheet and tooling affect the quality of the formed component. The reasonable agreement between numerical and experimental results demonstrated the usefulness of finite element analysis for sheet-forming design and showed the importance of tool clearance and lubrication.

Guo et al. (2000) reported developments in the analysis and optimum design of sheet-metal forming parts using a simplified inverse finite element approach [10]. The method estimates strains and stresses in thin metallic components produced by deep drawing, using the final three-dimensional geometry of the part to determine the initial blank configuration and the material deformation. The study demonstrated that inexpensive computational methods can support the design of complicated industrial sheet-metal components and the estimation of deformation before tooling is manufactured, which is valuable in the early stages of die design.

Jamli and Farid (2019) reviewed the application of neural-network and computational-intelligence methods for predicting springback in sheet-metal forming [11]. Their review highlighted that springback depends on several interacting material and process parameters and that conventional finite element prediction can become computationally demanding. The authors discussed the potential of computational-intelligence approaches for supporting springback prediction, and they emphasized that accurate springback estimation is important for the dimensional accuracy of formed components.

Die materials [6], [12]. Reference works on tool materials and sheet-metal forming describe the selection of tool steels for punches and dies. D2 tool steel is a high-carbon, high-chromium cold-work tool steel that is widely used where wear resistance and dimensional stability are required, which makes it suitable for the active components that contact the sheet repeatedly. Structural plates that primarily transfer load and support the tooling are commonly made from lower-cost steels such as mild steel, provided they are thick enough to avoid excessive deflection. The combination of a hard, wear-resistant working surface and an economical structural body is therefore standard practice, although the thickness of the plates must be chosen with stiffness in mind.

Summary of the literature. Several themes emerge from the reviewed work. First, forming load and press tonnage are governed by sheet thickness, deformed perimeter, material flow stress, friction, and process parameters, and simple analytical estimates are widely used for preliminary press selection but require a design allowance [1]–[4]. Second, the quality of a formed component depends on clearance, lubrication, blank-holder force, and tool geometry, which have been examined experimentally and numerically [5], [9]. Third, finite element analysis is established as the main tool for predicting forming behaviour and springback, but its reliability depends on numerical parameters and constitutive modelling [7], [8]. Fourth, simplified inverse methods and computational-intelligence techniques offer faster alternatives for early design and springback prediction [10], [11]. Finally, the reviewed studies concentrate mainly on the sheet and its formability, and they provide comparatively little guidance on the structural verification of the die assembly and on press-capacity utilization for shallow components such as oil pans.

V. CONCLUSION

This review examined published work and established practice related to forming-die design and press capacity selection for automotive sheet-metal components. The literature indicates that forming load depends on sheet thickness, component geometry, material flow stress, friction, clearance, and blank-holder conditions, and that simple perimeter-based estimates are suitable for preliminary press selection only when supported by a design allowance. Tool materials

should be chosen according to function, with wear-resistant tool steel such as D2 for the punch and die block and economical mild steel for structural plates, provided stiffness is verified. Finite element simulation is the main tool for predicting thickness, strain, load, and springback, although its predictions depend on numerical parameters and material modelling, and inverse and computational-intelligence methods offer efficient supplements. Future research should validate simplified load formulas against measured press loads for shallow components, document the basis of design allowances and press-utilization margins, report structural checks of the die assembly including deflection and contact pressure, and use material data measured for the sheet being formed. Addressing these gaps can support more reliable forming dies and more rational press selection for automotive oil-pan manufacturing.

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